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6 SENSITIVITY STUDY OF MOLTEN CYCLOTOL 75/25, TNT, AND COMPOSITION B FILLED SHELLS SUBJECTED TO SECONDARY FRAGMENT IMPACT.

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Prepared by

10 Edmund J. Swider

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Picatinny Arsenal
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FOREWORD

An experimental program was conducted for the Department of the Army, U.S. Army Armament R&D Command (ARRADCOM), Dover, New Jersey to determine the impact sensitivity of TNT, Composition B, and Cyclotol 75/25 explosives in the 4.2 inch and 81 mm mortar shells. Also under this same program a Phase II was conducted for the Naval Surface Weapons Center (NSWC) under Picatinny Arsenal's jurisdiction to determine the vulnerability of simulated munitions to detonation, deflagration or production of a chemical reaction when impacted by massive brick wall fragments propelled at various selected velocities. This experimental work was conducted by IIT Research Institute (IITRI) as Phase I, ARRADCOM test series, and Phase II, NSWC test series, under contract DAAK-10-77-C-0115 This program was a continuation of three previous research efforts in secondary fragment impact sensitivity studies.

Edmund J. Swider was IITRI's project manager and received assistance from IITRI staff members, Messrs. M. Amor, D. Baker, J. Daley, C. Foxx, and Mrs. Hyla Napadensky. The cognizant technical monitors for ARRADCOM were Messrs. M. Leondi and R. Rindner and for NSWC were J. Petes and F. Porzel.

Respectfully submitted,

IIT RESEARCH INSTITUTE

Edmund J. Swider

Edmund J. Swider
Research Engineer
Fire and Safety Research

APPROVED:

Hyla S. Napadensky

Hyla S. Napadensky
Engineering Advisor
Manager, Fire and Safety Research

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A two phase experimental program has been completed which provides secondary fragment impact sensitivity data useful to designers of munition facilities. In the first phase the targets tests were 4.2 inch and 81mm shells. All target shells depicted the "just filled" condition of the loading operation where the Cyclotol 75/25, TNT, and Composition B is in the molten state. Threshold impact velocities for initiation by concrete fragments were

20. ABSTRACT (concl)

determined. An emperical model was developed which significantly reduces the number of tests, and which enables us to determine the impact sensitivity of an ammunition item.

In phase two the targets tested were simulated munition (torpedo warheads). All munition targets were at ambient temperature and were filled with PBXN-103, H-6, HBX-1, and HBX-3 explosives. The impact velocities at which brick wall fragments did not detonate the simulated munition were determined.

SUMMARY

In Phase I of this program, experiments have been conducted to determine the sensitivity of two munitions to secondary fragment impact. Cylindrical concrete projectiles of four different weights were used in the testing which simulated a concrete wall break-up which was subjected to an accidental explosion. The explosives were in a molten state [about 93°C (200°F)] to depict the "just filled" condition of the two target shells used. The targets tested, and the type of explosive fill used in this program were:

- 81 mm (M362A1) mortar shell filled with molten TNT
- 4.2 inch (M329A1) mortar shell filled with molten TNT
- 4.2 inch (M329A1) mortar shell filled with molten Composition B
- 4.2 inch (M329A1) mortar shell filled with molten Cyclotol 75/25

Sensitivity curves relating the secondary fragment velocity and mass, above which initiation could occur in the explosive system were determined for the above listed shells and fills. The equations for these sensitivity curves were derived through the "method of least squares" finally, a method is presented to minimize experimental impact testing and conservatively predict sensitivity curves for any explosive item.

A Phase II was inserted in the middle of this program to impact simulated munitions (torpedo warheads) with large brick wall fragments. The program was for the performance of impact testing and to do only minimal analysis with no conclusion or recommendations to be drawn by IITRI on these tests. Full coverage of this Phase II impact testing can be found in Reference 1.

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1. INTRODUCTION

The U.S. Army is presently conducting a modernization program to upgrade melt-loading and other munition production facilities. This upgrading includes the modernization of processes, equipment, and improved safety in facility operations. As part of the program, the internal and external structures of production facilities are being assessed for their ability to prevent or limit propagation of an explosive accident. The magnitude of the explosive loading must be determined and the consequences predicted. The structural specifications to resist the explosive loading must be determined and the consequences predicted. The structural specifications to resist the explosive loads should reflect the sensitivity of the material in the particular process being analyzed. Specifications based on material sensitivities that are too conservative (overly safe) result in greater costs in materials and construction. Specifications based on liberal sensitivity data (not safe enough) mean personnel and equipment are at greater risk.

The scope of Phase I in the present research program is focused on the "just filled" shells in a shell loading area. This is the area of munitions production where molten explosive is poured into empty shell casings. To limit the propagation of an explosion, the loading area is divided into smaller areas or bays which in turn limits the total amount of explosive in each bay. The concrete wall barriers between bays should serve to limit an accidental explosion in one bay from propagating to an adjacent bay. In the event of an explosion the dividing wall will break up and the concrete fragments will strike the explosive-filled shells. Fragments created by the break-up of the concrete structures are called secondary fragments and those created from the break-up of the donor charge casing are called primary fragments. Figure 1 shows the distinction between primary and secondary fragments and donor and acceptor charges. What is not known is the sensitivity of the acceptor explosive to impact from secondary fragments. The objective of this research effort was to determine the reaction threshold velocity for two munitions (4.2 inch and 81 mm mortar shells). Castable explosives are of interest in this study and this includes the three tested, namely, TNT, Composition B, and Cyclotol 75/25. This report presents results of sensitivity tests conducted to fill the information gap on these two acceptor munitions filled with the three castable explosives in the pour loading operation.

Three previous research programs on secondary fragment impacts have been completed (References 2, 3, and 4).

The results of the first two experimental programs highlighted one important fact that Composition B exhibits an increased sensitivity with increasing temperatures. The third effort was necessary to determine the effects of shell casings (the confinement) on the impact sensitivity, of two cast explosives (Composition B and TNT). A total of 55 experiments were conducted on four different items (4.2 inch, 81 mm, 120 mm, and 155 mm). These targets did span a wide range of casing wall thicknesses.

Also nine experiments were conducted on two variations of scaled models of the melt kettles. As a result of this third effort, secondary fragment velocity versus mass, sensitivity curves were constructed for three of the items (155 mm, 120 mm, and 81 mm shells filled with Composition B). However not enough data was collected on the 4.2 inch mortar shell filled with TNT to determine a sensitivity curve. One fact emerged from this effort by testing, that differences in confinement and/or shell casing geometries, does play a part in the determination of impact sensitivity of castable explosives.

As a logical extension of these previous efforts, this program was initiated to extend and finish the impact testing of the 4.2 inch mortar shell filled with TNT, Composition B, and Cyclotol 75/25 and to determine their sensitivity curves. The remainder of this program was expended on impact tests carried out on 81 mm mortar shells filled with TNT. A total of 51 impact tests were performed rendering four sensitivity curves. An assessment was made of the variations of impact sensitivity where in one case the munition casing was held constant (4.2 inch mortar casing) and filled with three different castable explosives (TNT, Composition B and Cyclotol 75/25). Also with one of the sensitivity curves from the previous program (Reference 4) and one from this program a second assessment was made of the variations of impact sensitivity when the munition casing was again held constant (81 mm mortar casing) and filled with two different castable explosives (TNT and Composition B). The equations for the sensitivity curves were derived and an interim empirical model is presented to minimize experimental testing and renders capability to predict the behavior of additional explosives, in certain confinements, under large concrete fragment impact conditions. With refinement this technique has the potential of eliminating a greater portion of experimental impact testing of new and/or additional explosive materials and has the capability of conservatively predicting the sensitivity curves.

In the middle of this experimental testing a Phase II was initiated to test the vulnerability of simulated munitions (torpedo warheads) to brick wall fragments. Simulated munition targets were impacted with brick wall fragments propelled at preselected velocities. The simulated targets were of the same geometric configuration but fabricated of different materials (steel and aluminum) and filled with four different explosives (PBXN-103, H-6, HBX-1, and HBX-3). The final report will only highlight certain tasks performed under Phase II, since this experimental work was completely covered in IITRI's Phase II report J6421, dated November 1978. IITRI was contracted to perform experimental testing and to do minimal analyses to satisfactorily conclude this phase of the program. All final analyses of these 21 tests performed were NSWC's and ARRADCOM's responsibility. Since only minimal analyses were performed, no conclusion or recommendations were drawn by IITRI on this Phase II testing.

2. EXPERIMENTAL PROGRAM

2.1 Phase I Design

In this section of the final report, a description is provided of all the targets tested in this program. Originally there were to be two targets used (155 mm howitzer shells and 81 mm mortar shells) filled with TNT and Amatax 20. However, the 4.2 inch mortar shell was substituted for the 155 mm howitzer shell and the fills were changed to TNT, Composition B, and Cyclotol 75/25. The selection of the 4.2 inch mortar shell was recommended since it has given some interesting results and not enough data was collected on this type of confinement. Secondly, the Amatax 20 was eliminated as a filler since ARRADCOM pointed out that it is not readily accessible, may never be used as a filler in future production, due to excessive costs and hygroscopicity. Lastly, the Composition B filler material was an addition to the program. Also in this section is a description of the experimental methods employed to obtain secondary fragment impact conditions and the test procedure followed in this experimental program.

2.1.1 Target Description

The most vulnerable conditions in the melt loading operation (with regard to secondary fragment impact) is when the molten explosive has been poured and is sitting in the shell at an elevated temperature. A loading funnel is used to assist in the loading operation and as a secondary function it holds extra explosive for make-up when the explosive cools. The munition in this state is called the "just filled" condition. Figure 2 depicts the 4.2 inch (M329A1) mortar shell in the "just filled" state with the loading funnel in position. All targets tested in this program were in this condition.

A series of tests have been conducted on two different shells filled with three different explosives. Following is a list of the test series performed:

- 81 mm (M362A1) mortar shell filled with TNT, 16 tests performed
- 4.2 inch (M329A1) mortar shell filled with TNT, 9 tests performed
- 4.2 inch (M329A1) mortar shell filled with Composition B, 11 tests performed
- 4.2 inch (M329A1) mortar shell filled with Cyclotol 75/25, 15 tests performed

Sketches of the 4.2 inch (M329A1) and the 81 mm (M362A1) mortar shells without the loading funnels and listing all important dimensions are shown in Figures 3 and 4 respectively. Also Figures 5 and 6 depict the 120 mm cannon shell and the 155 mm howitzer shell respectively. The summary of the pertinent information on the four target shells is shown in Table 1.

2.1.2 Concrete Fragments

Laced reinforced, and in some cases just concrete elements and/or barriers without lacing are used in structures designed to resist the explosive force of a high order detonation. The Army manual TM5-1300 (Reference 5) recommends the concrete standards specified in the American Concrete Institute (ACI) Building Code. This is a high early-strength Portland cement (Type III) with a minimum strength of 20684 kPa (3000 psi). To minimize the effect of spalling, the size of the aggregate is limited to less than 2.54 cm (1 inch). The concrete used in this program to simulate wall fragments was a nine bag mix of Portland cement with aggregate size less than 2.54 cm (1 inch). A local ready mix contractor poured all of the necessary concrete fragments. All concrete fragments were left in ambient air for at least 7 days to cure before being expended.

The simulated concrete wall fragments were fabricated from cardboard cylinders, which were cut to four lengths. Certain length to diameter ratio as well as weights were maintained for these test series. Figure 7 shows the cardboard tube assemblies into which the concrete was poured. This shape was selected to facilitate launching these concrete fragments from IITRI's high pressure air gun. The obturator mounted on the back side of the concrete fragment was of (high density) polyethylene and provided a good seal with the barrel on the air gun. Table 2 lists the nominal sizes and weights of the concrete fragments used in this program.

2.1.3 Air Gun Launcher

A high pressure air gun was used to launch the cylindrical concrete fragments at the targets. Figure 8 shows the gun's arrangement relative to the targets. The capabilities of the air gun are shown in Figure 9. A maximum chamber pressure of 17237 kPa (2500 psi) is normally selected for safe operation. With this limitation the maximum velocities for the nominal weight of fragments are listed in Table 2. Some differences have been observed between the velocities selected and the velocities obtained, and it has been concluded that these differences are due to wind effects on the fragments in flight and the friction between the fragment and the gun barrel as the fragment is being propelled out. Aiming of the gun was done with a laser placed in the barrel. The targets were then moved to the desired position and the laser removed before firing. An air compressor pumps air into a large holding vessel and this compressed air is then bled into the gun chamber prior to firing. In order to charge the gun to the higher desired pressure sometimes takes up to 1 hour. Each charging and firing of the gun is done remotely.

2.1.4 Test Procedure

In this program, normally one test could be conducted daily if all supporting items were on hand. The one test per day was limited primarily due to the melting of the explosives. The shells for this program were received empty with the necessary explosives being shipped in separately.

When target shells had to be filled with Composition B or TNT, they were filled prior to testing. At the time of testing these prefilled shells were placed in a hot water bath until the explosive was molten. An extra shell was heated with each two target shells and its molten explosive was used to fill the loading funnel placed on top of the target shells. This water bath heating to attain the "just filled" condition [attain a 93°C (200°F) temperature] took about three hours for the larger 4.2 inch shells. However, when Cyclotol 75/25 was to be tested in the 4.2 inch mortar shells, they could not be filled prior to testing. It would require agitation and a long time to melt Cyclotol 75/25 in just a boiling water bath. It was necessary for the Cyclotol to be melted in an agitated double boiler set up in one of the buildings at the range, poured into a plastic container, transported out to the site, and poured into the target shells. This arrangement required approximately a half day to get the targets filled and ready for impacting.

While the target shells were being preheated, the air gun was being prepared for firing. Each concrete fragment was weighed just before placing it into the gun barrel. The weighing scale was graduated into 2.27 kg (5 lb) increments and the increments were large enough so that it was possible to read the weights to plus or minus a half of one division, which gave us an accuracy of $\pm$ 1.13 kg ($\pm$ 2.5 lb).

A wooden test stand was fabricated for each test so that the target shells were positioned perpendicular to the flight of the concrete fragment projectile. Also the shells had to be propped up with a board so as not to tumble. See Figure 2 depicting the angled stand and the prop. A 2.54 cm (1 inch) thick steel witness plate 30.48 cm x 30.48 cm (12 inch x 12 inch) was used beneath the targets. In this witness plate two holes were cut to accommodate the threaded studs on the bottom of the 81 mm and the 4.2 inch mortar shell targets. In all tests two targets were used except for one test (test number 4.2-M-7) where a single target was used. The two targets increase the target area and therefore improve the probability of achieving a good hit. Also this additional target provides information as to the degree of reaction.

Concrete fragment actual velocities were determined from film records of each experiment. A fiducial marker with 30.48 cm (12 inch) increments was placed in the field of view of the cameras. Three cameras were used to film each event. Two were high speed Fastax cameras operating at approximately 4000 frames/sec peak. The third camera was a slower Bell and Howell camera operating at approximately 64 frames/sec. This slower camera was used to provide a back-up record in case the high speed cameras malfunctioned or possibly missed the event due to timing errors.

Timing, that is, the time relationship between opening the solenoid valve on the air gun's high pressure chamber and starting the cameras, was critical for all these experiments. The total running time for the Fastax high speed cameras with 30.48 m (100 ft) of film was approximately 2 seconds. It was desirable to catch the event on the high speed film

and preferably on the last half of the film footage where the cameras have reached their maximum speeds and are fairly constant. The timing of the cameras and gun solenoid is directly related to the expected velocity of the concrete fragment and this in turn is related to the fragment weight and gun chamber pressure. Selecting the timing was a matter of judgment, experience and thorough scrutiny of previous data to predict the relationships. Additional uncontrollable factors, such as friction between gun barrel and the cardboard tube surrounding the concrete fragment, and wind also affect the timing.

In the experimental setup a chromel-alumel thermocouple was attached to the number 1 target's (target on the right as viewed from the gun) outer surface after setting up the target shells. The surface temperature near the center of the shell was monitored with a thermocouple attached on the surface with fiberglass tape. Also the explosive temperature was monitored by dipping a thermocouple directly into the center of the molten explosive. Lastly the ambient test site temperature was recorded. Fiberglass insulation, approximately 7.62 cm (3 inches) thick, was placed around the target shells to reduce heat loss. This insulation was especially important during the colder weather and at higher gun chamber pressures requiring more time to bring the chamber up to the desired pressure. It was concluded that the fiberglass insulation is of no significance in the impact mechanism.

2.2 Phase II Design

In this section a short description is provided of the targets tested in Phase II of this program. Simulated munitions filled with four types of explosives were supplied by NSWC for this experimental testing. Also in this section is a short description of the experimental methods employed to obtain secondary fragment impact conditions and the test procedures followed in this phase of the program. The majority of Phase II tasks consisted of experimental testing with only cursory analyses being performed by IITRI. This was mutually agreed upon by all of the participants, that IITRI was to perform the experimental testing, while NSWC and ARRADCOM would scrutinize the test results, reduce the data and perform the necessary analysis. Note that only short descriptions are provided in this section, however more details can be found in report Reference 1.

2.2.1 Target Description

NSWC had supplied a total of 15 simulated munition targets. These targets were cylindrical, approximately 30.5 cm (12 inches) in diameter and 33.0 cm (13 inches) high. Some of the cylinders were fabricated from steel plates and sheets, while others were fabricated from aluminum sheets. Three simulated munitions were filled with H-6 explosive, three with HBX-1 explosive, three with HBX-3 explosive and six with PBXN-103 explosive.

2.2.2 Brick Wall Fragments

In all of these Phase II experimental tests the impacting projectile consisted of mortared common bricks strapped together. Each brick fragment had ten common bricks mortared together, five coarse deep, and each coarse rotated 90 degrees. These brick wall fragments were slipped into cardboard tubes with an approximate 30.5 cm (12 inch) outside diameter. Again this shape was selected to facilitate launching these brick wall fragments from IITRI's high pressure air gun. An obturator was mounted on the back side of the brick wall fragment to provide the necessary sealing with the barrel of the air gun. The open area between the bricks and tube was filled with foam. The overall dimensions of the brick wall fragments were 30.5 cm (12 inches) in diameter and 40.6 cm (16 inches) long with an average weight of 34.8 kg (76.8 lb).

2.2.3 Test Procedure

This entire Phase II experimental testing was performed at IITRI's explosive test facility located near La Porte, Indiana. The brick wall fragments were launched from an air gun with the 30.48 cm (12 inch) diameter tube attached. IITRI's air gun facility is capable of launching large fragments at high velocities.

In this type of testing normally one test could be conducted daily if all supporting items are on hand. All the simulated munition targets were received fully loaded from NSWC. A wooden test stand was fabricated for each test so that the simulated munition target was positioned perpendicular to the flight of the fragment. Single targets were used and the plan was to impact the targets on its centerline and in the middle of its height. Over each target was constructed a wooden canopy laminated with a steel plate on top to prevent and/or slow down the fragments from the simulated munition target from flying down range in case of a detonation.

It was requested for this phase of work to record pressures and time of arrival at preselected distances from the detonation point. IITRI set up the necessary instrumentation and obtained time-pressure traces for each test. Proper triggering of the instrumentation was necessary and a foil switch was used for this triggering. IITRI fabricated all necessary foil switches, and in each test a foil switch was wrapped around the simulated munition target. At impact the fragment would close the switch which would in turn trigger the sweep across the oscilloscope screen. Two oscilloscopes were used, one as backup set at double amplitude and sweep.

Brick wall fragment actual velocity was determined from film records of each experiment. A fiducial marker with 30.48 cm (12 inch) increments was placed in the field of view of the cameras. Three cameras were used to film each event. Two were high speed cameras operating at approximately 4000 frames/sec peak. The third camera was a slower one operating at approximately 64 frames/sec. This slower camera was used to provide back-up record in case the high speed cameras malfunctioned or possibly missed the event due to timing error.

3. EXPERIMENTAL RESULTS

In this chapter the raw experimental data is presented. This will include visual observation of the fragment, witness plates, and targets together with the analysis from the film records of the projectile velocity, location of hit, and impact results. An overall summary of the experimental results is found in Tables 3 through 10 inclusive. The first section of this chapter presents the method used to determine the velocity of the concrete fragment projectile. Subsequent sections present results for the targets tested in Phase I ARRADCOM test series.

In the Phase II NSWC test series, all of the raw experimental data is presented in the report and Appendix of Reference 1. Therefore only some highlights will be repeated in this section of the final report.

3.1 Secondary Fragment Velocity Determinations

To calculate the concrete and/or brick wall fragment velocity, a time and motion high speed projector was used. Velocities were determined from the high speed film records obtained. The first step was to calculate the film speed at the event. This was accomplished by the following procedure and equation:

- measure a number of frames to obtain arithmatic average of film frame size (F_a in cm)
- measure a length over some selected number of timing spots (L in cm)
- selected number of timing spots (N_t)(note each timing spot represents 1 msec)

$$\text{FILM SPEED} = V_f = \left(\frac{L}{F_a\ N_t}\right) \cdot \left(\frac{1}{10^3}\right) \text{ frames/sec} \qquad (1)$$

Next the event had to be observed over a selected projected length on the fiducial marker and the number of frames counted for the fragment to traverse this length. However two types of corrections of the projected displacement had to be made due to the relative position of the fiducial marker. One correction was made because in some tests the marker was beyond the centerline of the concrete fragment path and the second because the angle at which the fiducial marker was placed was different from that of the fragment flight path. The following equation made the necessary corrections of the projected displacement:

$$\text{CORRECTED PROJECTED DISPLACEMENT} = \Delta X = \left[\frac{d_c}{d_f}\right] \cdot \left[\cos\,(\alpha_2 - \alpha_1)\right] \qquad (2)$$

where d_c is the distance from the camera to the centerline of the fragment path [in this program's test series this distance was constant 26.82 m (88 ft)], d_f is the distance from the camera to the fiducial marker

[in this program's Phase I test series this distance was either 26.82 m (88 ft) or 27.82 m (91 ft) while in Phase II this distance was 27.66 m (90.75 ft) or 31.22 m (102.42 ft)], α_2 is the angle from the horizontal to the fiducial marker, α_1 is the angle from the horizontal to the centerline of the fragment flight path.

Then the fragment velocity could be calculated using the following equation:

$$\text{VELOCITY} = V = \left[\frac{\Delta X}{N_f}\right] \cdot \left[V_f\right] \tag{3}$$

where N_f is the number of frames over the measured displacement.

We were also prepared with a back-up method for the cases when the timing lights would burn out or malfunction. The maximum speed of the Fastax camera can be adjusted by regulating the supply voltage to the camera. If the supply is maintained constant, the camera's speed profile (frames per second versus time) should be fairly reproducible. Also, the camera speed versus the number of frames from the start (time zero) should be constant for each test where the supply voltage was the same. Figure 10 was therefore constructed and used to estimate the camera speed in cases where it could not be determined by the method previously described. All that is necessary is to count the number of frames from the start of the film to the point at which impact occurs and then consult Figure 10 for the estimated film speed (V_f).

In cases when the Fastax high speed camera coverage was completely inoperable, the velocities could be calculated in a similar manner from the back-up slow speed Bell and Howell film coverage. In this case, the film speed was assumed to be a constant 64 frames/sec.

In Phase I, ARRADCOM test series, nine of the tests, the high speed camera coverage was lost; while in the Phase II, NSWC test series, only one was lost. For four of the tests, the event was first and then the film, indicating late timing of the cameras and for six tests the film was first then the event indicating early timing of the cameras. In these tests, other means were used to calculate the fragment velocity. Some were calculated from the slow speed back-up camera's film coverage; others were estimated from similar tests having the same fragment weight and chamber pressure, while others were estimated by comparing desired velocities and pressures to the actual obtained in previous executed tests. These velocities when appearing in this report or tables are preceded by the approximate sign (~). It is interesting to note that in Phase II testing, as well as in the last group of tests in Phase I tests with targets filled with Cyclotol 75/25, detonations resulted from low velocities. Testing had to be extended into the low velocity region, in order to bracket certain categories. In this low velocity region, only a few experiments were performed and timing data for the cameras was very sparse.

3.2 Aiming Point Selection

Under Phase I testing, as it was conjectured in previous shell impact tests, the shells should be impacted at the intersection of the top of the number 1 target shell and its loading funnel (at the shell-funnel juncture). The collapse of the top of the shell should pinch off the molten explosive from gushing out and place the trapped explosive under high pressure thereby increasing the vulnerability of the tested munitions. Due to this conclusion, all of this program's Phase I aiming points were planned at this intersection. However, due to varying wind velocities, gun tube friction and fragment instability, some impact points went slightly astray. For Phase II testing, the impact point selection is described in the second paragraph under "2.2.3, Test Procedure". The actual hit locations for all the Phase I experimental tests are depicted in Tables 3 to 6 inclusive. Also Tables 7 through 10 are included listing the experimental data and hit points from previous programs (References 3 and 4) for 81 mm mortar shells, 120 mm cannon shells, and 155 mm howitzer shells filled with Composition B. Phase II hit locations are depicted in Table 2 and the Field Data Sheets in report Reference 1.

In Phase I tests, two targets were used and the plan was to impact target 1 on its centerline and at the intersection juncture between shell and loading funnel. Target 1 was always the primary target and on the right when looking down the gun tube. Target 2, the secondary target, was always on the left.

Finally, some of the aiming points went astray due to the fragment instability. In some tests, the fragments came in nose down or up and in some of the lighter fragments they even came in sideways with the obturator either on top or bottom.

3.3 Mortar Shell 4.2 Inch (M329A1) - TNT Filled

This program's Phase I was initiated by performing an additional nine tests to complete and confirm results from previous research program (Reference 4), using the 4.2 inch mortar shell as the confinement. As reported in the final report of the previous program "not enough data was collected on the 4.2 inch mortar shell, TNT filled, to determine the sensitivity curve". With the additional nine and the previous thirteen sufficient data was collected to construct a velocity versus mass sensitivity curve. This experimental test data is listed in Table 3.

3.3.1 Nominal Concrete Fragment Weight of 29 kg (63 lb)

A total of seven experiments have been conducted with concrete fragments in this weight category and four were high order detonations while three were of the no reaction type. However, four were performed on a previous program (Reference 4).

In the four high order detonations the concrete fragments were propelled at the following actual velocities:

Previous program data, Reference 4

4.2-S-1 at 273 m/sec (896 ft/sec-Δ*)
4.2-S-3 at 226 m/sec (741 ft/sec-Δ)

Present program

4.2-S-5 at 184 m/sec (604 ft/sec-Δ)
4.2-S-6 at 150 m/sec (493 ft/sec-Δ)

In tests 4.2-S-1 and 4.2-S-5 where a detonation resulted, only a few small to medium size metal fragments were recovered. Similar fragmentation resulted in test 4.2-S-3 and 4.2-S-6; however, the metal fragments were considerably larger. Initiations in these tests occurred at approximately 0.5 msec after initial contact with the target shell.

Two tests were performed at lower velocities and one at a higher velocity that did not cause any explosive reaction.

3.3.2 Nominal Concrete Fragment Weight of 50 kg (110 lb)

A total of six tests were conducted at this weight with four tests resulting in high order detonations and two tests being of the no reaction type. The four high order detonation tests were performed on a previous program (Reference 4).

The concrete fragments in the four high order detonations, were propelled at the following actual velocities:

Previous program data, Reference 4

4.2-MS-1 at ~236 m/sec (~774 ft/sec-Δ)
4.2-MS-2 at 201 m/sec (659 ft/sec-Δ)
4.2-MS-3 at 123 m/sec (404 ft/sec-Δ)
4.2-MS-4 at 146 m/sec (480 ft/sec-Δ)

Two tests in this program were performed at lower velocities, so that a bracketing could be accomplished for this weight category. Both tests resulted in no reactions. In these two tests 4.2-MS-5 and 4.2-MS-6, the concrete fragment came in slightly low, but on the centerline of the target 1 shell. Target 1 shells, in both of these tests were flattened as well as ripped open, and with the base plates torn loose. Target 2 shells were flattened on the side and the base plates were torn loose.

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*The delta Δ symbol used in the sensitivity curves and here, indicates a high-order detonation.

3.3.3 Nominal Concrete Fragment Weight of 91 kg (200 lb)

Five tests were conducted using this weight of concrete fragments with two of the tests resulting in high order detonation, one with a burning and/or low order reaction, and two with no reaction. Four of these tests were performed on the previous program (Reference 4), while only one was necessary to bracket this weight category on the present program.

The concrete fragments in the two high order detonations and the one low order reaction were propelled at the following actual velocities:

Previous program data, Reference 4

4.2-M-2 at 168 m/sec (551 ft/sec-∇*)
4.2-M-3 at 161 m/sec (528 ft/sec-Δ)
4.2-M-4 at 97 m/sec (318 ft/sec-Δ)

In all the high order detonations, the concrete fragments hit the target shells at the desired locations and only small metal fragments were recovered after the tests.

Test 4.2-M-5 on this program was performed at an actual velocity of 71 m/sec (234 ft/sec) and test 4.2-M-1 from the previous program was performed at a velocity of ~176 m/sec (~576 ft/sec). Both of these tests resulted in a no reaction, and both concrete fragments hit slightly to the right of target 1.

In shot 4.2-M-2 the target shell was recovered with the top squeezed shut and some molten TNT left inside. In observing the film a small flash and some black cloud appeared after impact. The initiation was at the top of the shell where the funnel joins the shell. It seems that the reaction did not propagate to the rest of the explosive in the shell and for this reason it was called a burn or low order reaction.

3.3.4 Nominal Concrete Fragment Weight of 179 kg (395 lb)

A total of four tests were conducted with this weight of concrete fragments, and only one resulted in a high order detonation while three tests resulted in no reactions.

The one test that resulted in a high order detonation was performed on the previous program (Reference 4). The concrete fragment was propelled at a velocity of 143 m/sec (470 ft/sec). Only small to medium size metal fragments were recovered after the test. The three no reaction tests conducted on this program were at lower fragment velocities. In test 4.2-L-2 the concrete fragment hit the target shell at the centerline but slightly low and was classified as a "good hit". However, in test 4.2-L-3 and 4.2-L-4 the concrete fragments came in too high and only sheared off the loading funnels.

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*The upside down delta ∇ symbol used in the sensitivity curves and here, indicates a low order reaction.

3.4 Mortar Shell 81 mm (M362A1) - TNT Filled

A total of 16 experimental tests were performed on this program using the 81 mm mortar shell as the confinement. Of these tests only two resulted in high order detonations and two were classified as low order reactions. The remaining 12 tests resulted in no reaction. Sufficient data were gathered to construct a velocity versus mass sensitivity curve. In this section of the report the tests performed for each concrete fragment weight category will be described separately. This experimental test data is listed in Table 4.

3.4.1 Nominal Concrete Fragment Weight of 30 kg (66 lb)

A total of four experiments were conducted with concrete fragments in this weight category and all four were of the no reaction type. In test 81-S-6 the concrete fragment came in too low and to the right while in test 81-S-8 it came in too high and to the left, and in both of these tests the hits were classified accordingly. In the other two tests, 81-S-7 and 81-S-9, the concrete fragments hit the target shells at the desired location.

In test 81-S-7 the target 1 shell was completely flattened and the bottom one-third ripped open, while on target 2, the top one-third was flattened but the shell was intact. In test 81-S-9 only metal pieces of the shells could be found and the upper portions of the loading funnels. The molten TNT was strewn around the area, but no reactions ensued.

3.4.2 Nominal Concrete Fragment Weight of 51 kg (112 lb)

A total of four tests were conducted at this weight with two of the tests resulting in high order detonations and one test recorded as a low order reaction. Only one test was of the no reaction type.

The concrete fragments in the three reacting experiments were propelled at the following actual velocities:

81-MS-5 at 219 m/sec (718 ft/sec-∇)
81-MS-6 at ~268 m/sec (~880 ft/sec-Δ)
81-MS-7 at 196 m/sec (644 ft/sec-Δ)

Test 81-MS-8 with the concrete fragment propelled at the lowest velocity in this weight category resulted in no reaction. This test's fragment was propelled at 181 m/sec (595 ft/sec) and only metal pieces of the two targets and one part of a loading funnel were recovered after the test.

In all four of these tests the concrete fragment impacted the target shells at the desired locations.

In shot 81-MS-5 the target 1 shell was recovered. The top portion was smashed flat and the bottom split open. In observing the film record of this shot, some slight burning was visible just after impact. The initiation appeared to be at the bottom of the shell where it split open. From the inspection after the test it seems that the reaction did not propagate to the rest of the explosive and for this reason it was classified as a burn or low order reaction.

3.4.3 Nominal Concrete Fragment Weight of 88 kg (194 lb)

Four tests were conducted using this weight of concrete fragments with all four tests resulting in no reaction. In test 81-M-6 the concrete fragment came in too far to the right and clipped the loading funnel of target 1. Target 2 was intact and showed no damage. Again in test 81-M-7 the concrete fragment came in high between the two targets and sheared off the funnels. In test 81-M-8 and 81-M-9 the concrete fragment struck the targets in the desired location, but no reaction occurred. In the latter test only large metal pieces were recovered from either target, while in the other test (81-M-8), target 1 was found smashed flat and in four pieces while target 2 was only dented on the right side. Some molten TNT was found in the area but no signs of detonations or burning were discovered.

3.4.4 Nominal Concrete Fragment Weight of 175 kg (386 lb)

A total of four tests were conducted with this weight of concrete fragments, and only one resulted in a low order reaction. The other three tests were recorded as no reaction.

In test 81-L-5 the concrete fragment came in with its nose down thereby striking the target shell low. In the film study of the test there was an indication of some burning or detonation at impact. Also range personnel reported a loud report at impact, and only two metal pieces were recovered on target 1. Target 2 with the loading funnel intact was found in the area. Due to the above mentioned observations it was concluded that this test be recorded as a low order reaction.

In tests 81-L-6 and 81-L-7 the concrete fragment impacted the top of the loading funnels and were slightly to the left. The final test in this weight category 81-L-8 was a good hit, at the desired location, and only two metal pieces could be found after the test of target 1. Target 2 was intact but its loading funnel was missing. Film study of this test indicated no reaction. In these three no reaction tests the concrete fragments were propelled at lower velocities than the one resulting in a reaction.

3.5 Mortar Shell 4.2 Inch (M329A1) - Composition B Filled

A total of 11 experimental tests were performed on this program using 4.2 inch mortar shells as confinement and filled with molten Composition B. Of the 11 tests only one was of high order detonation and two

were recorded as low order reactions. The other eight tests were recorded as no reactions. Minimal data was gathered in this series, however, there was sufficient data to construct a velocity versus mass sensitivity curve. In this section the tests performed for each concrete fragment weight category will be described separately. This experimental test data is listed in Table 5.

3.5.1 Nominal Concrete Fragment Weight of 29 kg (65 lb)

Two experimental tests were performed on this program using the 4.2 inch mortar shell as confinement. One test was recorded as a high order detonation and one test resulted in no reaction.

In test 4.2-S-9 the concrete fragment was propelled at an actual velocity of 256 m/sec (839 ft/sec-Δ) and impacted target 1 at the desired location. The film study indicated a high order detonation ensued at impact, and the explosion of target 1 threw target 2 into the air where it remains through the entire high speed film coverage. Target 1 was split wide open while target 2 remained intact with only its base plate torn loose.

In the no reaction test number 4.2-S-8 the concrete fragment was propelled at a lower velocity. The fragment came in to the left, so that target 2 was hit at the desired location. The upper half of target 2 was flattened, while target 1 was just slightly dented.

3.5.2 Nominal Concrete Fragment Weight of 52 kg (115 lb)

A total of three tests were conducted at this weight with one of the tests resulting in a low order reaction while two tests were of the no reaction type.

The one test 4.2-MS-7 that resulted in a low order reaction was impacted with the concrete fragment propelled at a velocity of 148 m/sec (485 ft/sec-∇). The concrete fragment came in at the desired location and target 1 was split open and bulged at the bottom. Target 2 was recovered with only a nick at the top but intact.

In tests 4.2-MS-8 and 4.2-MS-9, that resulted in no reactions, the concrete fragments came in at the desired location. Both targets were recovered from these two tests and targets 1 were flattened and split while targets 2 were dented and caved in. One of these test's concrete fragment was propelled at a lower velocity and the other at a higher velocity than the reaction test.

3.5.3 Nominal Concrete Fragment Weight of 91 kg (201 lb)

Three tests were conducted using this average weight of concrete fragments with all three tests resulting in no reaction. In tests 4.2-M-6 and 4.2-M-8 the concrete fragments came in slightly high, but close enough to the desired location to be considered as "good hits". Both targets 1

were recovered and the upper half of the shells were caved in and crushed. Targets 2 showed only slight top edges dented and loading funnels crushed.

In test 4.2-M-7 only one target shell was used. This test is the only one with one target, in all other tests two targets were used. The concrete fragment impacted the target at the desired location and crushed in the upper half of the shell. The heavy threaded nose piece and loading funnel could not be located after the test.

3.5.4 Nominal Concrete Fragment Weight of 178 kg (393 lb)

A total of three tests were conducted with this weight of concrete fragments, only one resulted in a high order detonation. The other two tests were recorded as no reaction.

In the high order detonation, test 4.2-L-6 the concrete fragment was propelled at the fastest velocity in this category, which was ~122 m/sec (~400 ft/sec-Δ). Only two metal pieces were recovered of target 1, while target 2 was totally flattened and bowed with a deep dish in the center.

Test 4.2-L-5 resulted in a no reaction although the concrete fragment did impact the targets at the desired location. Both targets were recovered and the upper two-thirds of target 1 was flattened, while about one-half of target 2 was flattened. In the final test of this category, 4.2-L-7, the concrete fragment did impact the targets slightly high and to the left. Both targets were recovered after the test and both showed signs of the top edge being grazed by the fragment. The two loading funnels were smashed flat. This final test resulted in a no reaction.

3.6 Mortar Shell 4.2 Inch (M329A1) - Cyclotol 75/25 Filled

A total of 15 experimental tests were performed on the program using the 4.2 inch mortar shell as confinement and filled with molten Cyclotol 75/25. Of the 15 tests, six were of the high order detonation and one test was classified as a low order reaction. The remaining eight tests resulted in no reactions. Sufficient data were gathered to construct a velocity versus mass sensitivity curve. However in one weight category, namely the 52 kg (115 lb) category, the data indicated that this target munition filled with molten Cyclotol 75/25 is more sensitive than any of the other categories in this series of tests. In this section of the report the tests performed for each concrete fragment weight category will be described separately. This experimental data is listed in Table 6.

3.6.1 Nominal Concrete Fragment Weight of 29 kg (65 lb)

Three experimental tests were performed using targets of 4.2 inch mortar shells filled with Cyclotol 75/25. One test was recorded as a high order detonation and two tests resulted in no reaction.

In test 4.2-S-12 that resulted in the high order detonation, the concrete fragment was propelled at a velocity of 261 m/sec (858 ft/sec-Δ).

Also this fragment came in sideways with obturator on top, but did impact the target in the desired location. Only about four metal pieces were recovered of target 1 while target 2 was dented on the side and had the threaded nosepiece missing.

In test 4.2-S-11 that resulted in a no reaction the concrete fragment was propelled at a velocity of 228 m/sec (749 ft/sec) and again came in sideways with obturator on top. The fragment did impact the targets at the desired location. Both targets were recovered, with the upper half of target 1 flattened and split open while target 2 was caved in at the top. Both loading funnels were missing. On test 4.2-S-10 the concrete fragment came in slightly low but on the centerline of target 1. After the test both targets were recovered with target 1 split wide open and smashed while target 2 was only dented on the side. Both funnels were recovered intact with only their stems broken off. In the tests that resulted in a no reaction the molten Cyclotol was strewn around the impact area.

3.6.2 Nominal Concrete Fragment Weight of 52 kg (115 lb)

A total of five tests were conducted at this weight with three of these tests resulting in a high order detonation while two tests were of the no reaction type.

In the three high order detonations the concrete fragments were propelled at the following actual velocities:

4.2-MS-10 at 178 m/sec (583 ft/sec-Δ)
4.2-MS-11 at ~101 m/sec (~330 ft/sec-Δ)
4.2-MS-12 at ~ 84 m/sec (~275 ft/sec-Δ)

In tests 4.2-MS-10 and 4.2-MS-11 where a detonation resulted, only a few small metal fragments were recovered. Also in the first test the witness plate was broken into six pieces and in the second test it was badly bowed. In both cases the witness plates had to be replaced. In test 4.2-MS-12 only one piece of metal was recovered of target 1 and the base plate, while target 2 was intact but dented on the side.

In test 4.2-MS-13 the targets were to have been impacted with the concrete fragment at a velocity of 61 m/sec (200 ft/sec) but due to an unexpected chamber pressure drop it was propelled only at 49 m/sec (160 ft/sec). Since the targets were set in a position for the faster velocity, the result was that the fragment hit the ground about 2 ft in front of the targets and tumbled into them. No reaction was recorded due to this tumbling action.

Test 4.2-MS-14 was performed as a repeat of test 4.2-MS-13 and the concrete fragment was propelled close to the desired velocity of 61 m/sec (200 ft/sec). Film studies show the actual velocity at 59 m/sec (193 ft/sec). The targets were impacted at the desired location with no reaction. Targets were recovered and target 1 was flattened while target 2 was intact with only a slight dent.

Note in this weight category detonations were experienced at some fairly low velocities, namely at ~84 m/sec (~275 ft/sec). Also initiations started approximately at 0.25 msec after contact.

3.6.3 Nominal Concrete Fragment Weight of 89 kg (197 lb)

Three tests were conducted using this average weight of concrete fragments with one test resulting in a high order detonation, one in a low order reaction and one test recorded as no reaction. In this category as the concrete fragment's velocity was increased in each successive test, the results went from no reaction to low order reaction to high order detonation.

The concrete fragments in the two detonating tests were propelled at the following actual velocities:

4.2-M-9 at 146 m/sec (478 ft/sec-Δ)
4.2-M-11 at ~105 m/sec (~345 ft/sec-∇)

Also in both of the above tests the concrete fragments came in with the nose up but did impact the targets in the desired location. In the first test the nose was up approximately 12 degrees and in the second approximatly 6 degrees. In the high order detonation, test 4.2-M-9, only metal fragments were recovered of the targets and the witness plate was bowed. In the low order reaction, test 4.2-M-11, both targets were recovered and both were flattened, split and the base plates torn loose.

In the test that resulted in a no reaction, test 4.2-M-10, the concrete fragment came in slightly low and both targets were flattened with target 2 base plate torn loose.

3.6.4 Nominal Concrete Fragment Weight of 175 kg (386 lb)

A total of four tests were conducted with this average weight of concrete fragments, and only one resulted in a high order detonation. The other three tests were recorded as no reaction.

In the high order detonation, test 4.2-L-8, the concrete fragment was propelled at a velocity of 95 m/sec (313 ft/sec-Δ). Only small metal fragments were recovered together with one base plate from one of the target shells.

Test 4.2-L-9, 4.2-L-10, and 4.2-L-11 resulted in no reactions, however, the concrete fragments were propelled at slower velocities and in two of the tests (4.2-L-9 and 4.2-L-10) impacts were somewhat low striking the witness plate and target shells. All target shells were dented with target 1 receiving the greatest damage. The Cyclotol was strewn around the impact area after each of these tests.

3.7 Simulated Munitions Filled with PBXN-103 Explosive

Six simulated targets filled with PBXN-103 were supplied by NSWC. Three of these targets had as their confinement aluminum sheeting 0.368 cm (0.145 inch) thick, and three of steel plate 0.636 cm (0.250 inch) thick. All targets with PBXN-103 were cylindrical, with an outside diameter of 33.0 cm (13 inches) and 33.0 cm (13 inches) long.

A total of seven tests were conducted using PBXN-103 filled targets. One target was used twice. Of the seven tests, four tests produced some burning and/or reaction. In two of these tests the target containers were found up the range with all of their explosive consumed.

3.8 Simulated Munitions Filled with H-6 Explosive

Three simulated targets filled with H-6 explosive were supplied by NSWC. These three targets had as their confinement steel sheeting 0.318 cm (0.125 inch) thick. All targets were cylindrical with an outside diameter of 28.6 cm (11-1/4 inches) and 28.6 cm (11-1/4 inches) long.

Three tests were conducted using H-6 filled targets. All these tests resulted in no reaction. The impacting brick wall fragments were propelled at 61 m/sec, 109 m/sec and 243 m/sec (201 ft/sec, 356 ft/sec, and 797 ft/sec). Note the steadily increasing velocities and still no reactions resulted.

3.9 Simulated Munitions Filled with HBX-1 Explosive

Three simulated targets filled with HBX-1 explosive were supplied by NSWC. These three targets had as their confinement steel sheeting 0.318 cm (0.125 inch) thick. All targets were cylindrical with an outside diameter of 28.6 cm (11-1/4 inches) and 28.6 cm (11-1/4 inches) long.

Three tests were accomplished using HBX-1 filled targets. All three tests resulted in no reaction. Again the fragment velocity was increased from 60 m/sec to 249 m/sec (196 ft/sec to 816 ft/sec) with no burning or detonation recorded.

3.10 Simulated Munitions Filled with HBX-3 Explosive

Three simulated targets filled with HBX-3 explosive were supplied by NSWC. These three targets had as their confinement aluminun sheeting 0.318 cm (0.125 inch) thick. All targets were cylindrical with an outside diameter of 28.6 cm (11-1/4 inches) and 28.6 cm (11-1/4 inches) long.

Three tests were accomplished using HBX-3 filled targets. Again the fragment velocity was increased from 62 m/sec to 247 m/sec (203 ft/sec to 812 ft/sec) with no burning or reaction recorded.

4. ANALYSIS OF DATA

In this chapter some fundamental relationships between the variables in a secondary fragment impact experiment will be presented. As an obvious first consideration, the parameters characterizing the actual impact, i.e., fragment mass and velocity, will be related. This establishes the available kinetic energy and momentum but says nothing of the dynamics of the impact, the efficiency of the energy transfer process or the rate of energy transfer to the explosive. These variables are in some way related to the properties and geometries of the shell casing, explosive, and concrete fragment. The importance of the location of impact will also be discussed since various casing geometries will react or deform differently depending on where the loading is applied.

Only Phase I, ARRADCOM test series, experimental data analysis will be covered in this section of the final report. Phase II NSWC test series, data analysis was mutually agreed to be the responsibility of NSWC and ARRADCOM. All necessary measurements, field data, tables, photos, film coverage and Phase II report were turned over to NSWC for the task of data reduction and analysis.

4.1 Mass-Velocity Sensitivity Curves

Fragment velocity versus fragment mass data has been plotted to depict the target sensitivity to secondary fragment impact stimuli. The boundary velocity representing the estimated threshold initiation conditions was determined for the 4.2 inch, 81 mm mortar shells, 120 mm cannon shells and 155 mm howitzer shells.

The plots of the data are shown in Figures 11 through 17 inclusive. All data points plotted in the sensitivity curves were considered to be equal. That is, the details of each experiment were neglected and just the net results taken. No attempt was made to weigh any point with regard to how stable the concrete fragment was or where the fragment hit, or the severity of the impact. Impacts at the intersection of the top of the target shell and the loading funnel did show to increase the probability of initiation.

The pertinent data used to determine the boundaries for the sensitivity curves are shown in Tables 3 through 10 inclusive. Note Figure 11 has some carryover experimental test results from previous programs (Reference 4). Also Figures 15 through 17 inclusive are carried over from the previous program work with 81 mm mortar shells, 120 mm cannon shells and 155 mm howitzer shells filled with Composition B.

4.2 Momentum and Kinetic Energy

Using the threshold sensitivity curves, a total of six points were selected on each curve for which the momentum and kinetic energy was calculated. The calculated results are shown in Tables 11 through 14.

As one scrutinizes this data one notices that the momentum tends to increase in all cases, as the concrete fragment weight increases. At the same time the impact velocities decrease. For a given concrete projectile mass we see that the ordering of the threshold momentum for the seven shell/explosive combinations is as follows: 4.2 inch Cyclotol filled, 4.2 inch TNT filled, 4.2 inch Composition B filled, 155 mm Composition B filled, 81 mm Composition B filled, 81 mm TNT filled, 155 mm Composition B filled, 81 mm Composition B filled, 81 mm TNT filled and 120 mm Composition B filled.* Although the difference in momentum delivered to the 155 mm shell and the 81 mm shell is not great, we would have expected that for the same explosive fill (Composition B) the 81 mm shell would be much more sensitive than the 155 mm shell (i.e., required significantly less momentum delivered to it for initiation). This expectation is based on the fact that the 81 mm shell appears to be a weaker shell (both its t/D and L are much smaller than for the 155 mm shell). For the same explosive fill we expected that the strength of the shell would strongly influence its ease of initiation. This expectation was not realized. This indicates that momentum alone does not permit the prediction of sensitivities of various shells. Another interesting observation is that of kinetic energies. For the 81 mm mortar shells, the 120 mm cannon shells and the 155 mm howitzer shells, the energies oscillate somewhat as the concrete fragment weight increases. However, for the 4.2 inch mortar shells the energies always increase as the concrete fragment weight increases. Some of this was evident from the posttest observations of partially damaged concrete fragments, that in some cases the fragment transfers only a portion of its momentum and energy to the target and then continues on relatively unscathed. This means that some of the available momentum and energy is not transferred to the target.

The total mass of the acceptor explosive system (explosive plus casing) may be important for the following reason. The mass of the system provides an inertial force to resist the impact force trying to accelerate it. It is these two counteracting forces which to a certain extent determine how much and how fast the shell will be crushed.

Also it was observed that the smallest concrete fragments being used experienced the most destruction at impact with the targets, indicating that most if not all of its energy has been transferred to the targets. Using this as a criterion and calculating the kinetic energy for the smallest boundary point available on the graphs [the 23 kg (50 lb) concrete fragment], and establishing this kinetic energy as a constant, the other velocities were calculated. The resulting curves are superimposed in Figures 11 through 17. For the 81 mm mortar shell and the 155 mm howitzer shells the curves are almost identical; however, for the 4.2 inch mortar shell and the 120 mm cannon shells the constant energy curves dropped off dramatically as the mass of the fragment increased.

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*The ordering of the 120 mm Composition B filled shell does not hold at concrete weights of 181 kg (400 lb) and below 29 kg (65 lb).

One can conclude that using the above criterion gives a safe method of predicting the boundary condition for any castable explosive filler material for a particular target. To recapitulate, if experimentally the boundary condition is established for the 23 or 29 kg (50 or 65 lb) concrete fragment, all other larger concrete fragment boundary conditions [up to 181 kg (400 lb)] can be safely predicted through the kinetic energy calculations.

4.3 Derived Equations for Sensitivity Curves

Finally for each sensitivity curve two formulas were derived using the "method of least squares." In curve fitting there are two somewhat different interpretations. In one case we could ask for the equation of a curve that passes rigorously through each point of a selected set. In the second case for our curve fitting we simply can require that some simpler curve be obtained whose equation comes only close to each point selected. This second case is the recommended case for handling experimental data, and its solution is almost universally taken to be by the least-square criterion.

Using the method of least squares to fit six selected pairs of data points (the six selected pairs of data points are the same used in momentum and kinetic energy calculations) for each of the curves, a fit was made of the power curve equation, namely:

$$y = aX^n \tag{4}$$

$$V = aW^n \qquad \text{(our application)}$$

where V is the velocity of the fragment in meters per second and W is the weight of the fragment in kilograms. Solving Equation 4 gave one solution for this investigation's seven sensitivity curves.

Note however that in Figure 16 the sensitivity curve is a straight line when plotted on semilogarithmic cross section paper. This immediately indicates that the equation to best fit this curve is of the exponential form:

$$y = ae^{nX} \tag{5}$$

$$V = ae^{nW} \qquad \text{(our application)}$$

This is true in one case only and was calculated for that particular case. Under Figure 16 you will note this extra equation being listed.

Also since these curves do approach the parabolic equation, a fit again was made of this equation:

$$y = a + bX + cX^2 \tag{6}$$

$$V = a + bW + cW^2 \qquad \text{(our application)}$$

Solving Equation 6 gave another solution for the seven sensitivity curves. The following equations were derived:

<u>Power Equations</u> (Eq 4)

Figure 14	$V = 300\ W^{-0.31}$	(4.2 inch - Cyclotol 75/25)
Figure 11	$V = 440\ W^{-0.36}$	(4.2 inch - TNT)
Figure 13	$V = 500\ W^{-0.33}$	(4.2 inch - Composition B)
Figure 15	$V = 1060\ W^{-0.45}$	(81 mm - Composition B)
Figure 12	$V = 1350\ W^{-0.49}$	(81 mm - TNT)
Figure 16	$V = 900\ W^{-0.40}$	(120 mm - Composition B)
Figure 17	$V = 1050\ W^{-0.45}$	(155 mm - Composition B)

<u>Exponential Equations</u> (Eq 5)

Figure 16	$V = 267\ e^{-0.005W}$	(120 mm - Composition B)

<u>Parabolic Equations</u> (Eq 6)

Figure 14	$V = 132 - 1.0\ W + 0.004\ W^2$	(4.2 inch - Cyclotol 75/25)
Figure 11	$V = 165 - 1.3\ W + 0.004\ W^2$	(4.2 inch - TNT)
Figure 13	$V = 202 - 1.4\ W + 0.005\ W^2$	(4.2 inch - Composition B)
Figure 15	$V = 315 - 2.9\ W + 0.010\ W^2$	(81 mm - Composition B)
Figure 12	$V = 352 - 3.4\ W + 0.001\ W^2$	(81 mm - TNT)
Figure 16	$V = 267 - 1.4\ W + 0.003\ W^2$	(120 mm - Composition B)
Figure 17	$V = 307 - 2.8\ W + 0.010\ W^2$	(155 mm - Composition B)

As Equations 4 are scrutinized for the 81 mm mortar shells (Figures 12 and 15) the exponent "n" seems to be constant and approaches -0.5, while for the 4.2 inch mortar shells (Figures 11, 13 and 14) the exponent "n" again is somewhat constant and approaches -0.33. Thus the exponent "n" seems to be related to some physical property or characteristic of the shell; whereas the constant "a" seems to be dependent upon both the explosive and the shells.

Finally using the derived power equations a graph was drawn, Figure 18, with the exponent "n" of these equations along the abscissa and the constant "a" along the ordinate, through which a line was fitted. With the aid of this graph and the experimental establishment of the initiation

threshold velocity for the smallest concrete fragment one can derive the power equation which depicts the sensitivity curve for the tested target and expolosive fill. Through minimal experimental testing, and few calculations, one can derive the empirical power equation for the sensitivity curve of the explosive system in question.

Example: Let's assume for the 4.2 inch target shells filled with molten TNT and using the 23 kg (50 lb) concrete fragment we experimentally determined the initiation threshold velocity to be 144 m/sec (472 ft/sec). Using the power Equation 4

$$V = aW^n$$

and assuming the power "n" to be -0.3, -0.35, -0.4 and -0.45 we calculate and obtain four points,

$$V = aW^n \quad \text{or} \quad a = V/W^n$$

$$144 = a(23)^{-0.30} \qquad a = 369$$

$$144 = a(23)^{-0.35} \qquad a = 431$$

$$144 = a(23)^{-0.40} \qquad a = 505$$

$$144 = a(23)^{-0.45} \qquad a = 590$$

Next we plot these points (-0.30, 369), (-0.35, 431), (-0.40, 505), (-0.45, 590) on the graph in Figure 18 and draw a line through them. At the intersection of the two lines you pick off the most appropriate a = 395 and n = -0.33. Therefore the empirical power equation is:

$$V = 400\ W^{-0.33} \qquad \text{(Empirical)}$$

The derived equation using the method of least square (Figure 11) rendered:

$$V = 440\ W^{-0.36} \qquad \text{(Derived)}$$

See Table 15 which shows the accuracy between these two equations. For the remaining six shell/explosive configurations the empirical equations were determined from the graph. See Table 16 listing these equations. This model was also validated for these same configurations. Table 17 shows the accuracy between the two equations as compared to the experimental results.

It is believed that this method renders a reasonable power equation which does produce a fairly accurate sensitivity curve for certain explosive systems through minimal experimental testing. One word of caution at this point, this has only been proven for the munitions (81 mm, 120 mm, 155 mm and 4.2 inch) and explosives (TNT, Composition B and Cyclotol 75/25) that are being discussed in this report.

4.4 Confinement Effects

The effect of the shell casing or confinement on the secondary fragment mass/velocity sensitivity data will be discussed in this section. In an impact experiment the casing properties, primarily material strength, determine how much of the incoming energy will be used to crush or penetrate the casing and the amount of energy available for transfer to the explosive.

If it is assumed that the boundary velocity is directly proportional to the ratio D/t, where D is the maximum outside diameter and t is the wall thickness, then some method could be devised to proportion models to predict actual system conditions. It must be pointed out that in this program no scaling scheme was necessary, since the confinements were the actual mortar shells. The pertinent data concerning the actual confinements are shown in Table 1. The 4.2 inch mortar shell is seen to have a smaller wall thickness to diameter ratio than the 81 mm mortar shell. This could mean that it will provide less amount of resistance to external pressure. However the 81 mm mortar shells, provided by ARRADCOM and used on this program, had a groove 0.46 cm wide x 0.30 cm deep (0.182 inch wide x 0.120 inch deep) on its maximum outside diameter. When taking this into account then the 81 mm mortar shell would provide lesser resistance to external pressure. It is believed that the thickness to diameter ratio can be a dominant factor in secondary fragment impact tests, but first some standards must be established of what actually constitute the wall thickness as well as the diameter to be selected. This ratio is clouded since shell casings have grooves, reduced sections, ogives, rotating bands, and thick nose and base components. Also in certain cases a more accurate choice might be the minimum t/D ratio over the cross-sectional area the concrete fragment impacts. The 4.2 inch and 81 mm target shells had thicker threaded collars at the top and that is the area selected for the hit point in these tests. Finally both shells had thick base plates.

In the study of thin wall cylinders the t/D ratio is an important factor as are the stresses that result from external pressure. Cylinders having diameter-to-thickness (D/t) ratio greater than 10 (or $t/D < 0.1$) are usually considered thin-wall. Elasticity theory reveals (for thin wall cylinders) that the pressure is related to the stress and the t/D ratio:

$$P \propto \left(\frac{t}{D}\right)^1 \tag{6}$$

That is, the pressure (P) is directly proportional to the t/D ratio. Elasticity theory also shows that the collapsing pressure (P_c) is related to the t/D ratio to the third power (Reference 6):

$$P_c \propto \left(\frac{t}{D}\right)^3 \tag{7}$$

From the conservation of momentum the impact stress or pressure is proportional to impact velocity*; therefore since

$$P \propto V \quad \text{and} \quad P \propto \left(\frac{t}{D}\right)^3 \quad \text{(from Eq 7) then}$$

$$V \propto \left(\frac{t}{D}\right)^a \tag{8}$$

where "a" is expected to be between 1 and 3.

A crude correlation was found between the impact velocity for initiation and t/D, for the four different Composition B filled shells. This correlation existed if one considered the lowest velocity at which a reaction occurred (neglecting the weight of the concrete fragment). Similarly for the two TNT filled shells that were tested. The following Table 18 shows these relationships.

4.5 Explosive Properties

It is reasoned that the sensitivity of an explosive, that is, its propensity to be initiated by a certain stimulus will be affected by its geometry and thermodynamic state among other factors. This was clearly shown in References 2 and 3 where the secondary fragment impact sensitivity of Composition B filled 155 mm shells, increased with increasing temperatures of the explosive.

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*For the simple case, the impact of a solid metal cylinder on a rigid target, the following relationship holds (for the elastic region)

$$P = \frac{EV}{C_o}$$

where E is the modulus of elasticity and C_o is the velocity of propagation of an elastic wave. When $V > C_o$, the impacting material behaves as a fluid. The impact stress depends upon the initial velocity and density (ρ).

$$P = E\left(\frac{V}{C_o}\right)^2$$

where $C_o = \sqrt{E/\rho}$, and substituting we get $P = \rho V^2$.

Although the problem of concrete impacting an explosive filled projectile is more complicated than the simple example above, and the relationship between pressure and velocity will contain more terms, from the conservation of momentum, one can show that the pressure is directly proportional to the impact velocity (Reference 9).

The explosive was more sensitive at or above its recrystallization temperature ~77°C (~170°F) for Composition B. The data collected in this research effort for secondary fragment impacts of TNT, Composition B and Cyclotol 75/25 filled shells points to the complexity and difficulty in understanding how the explosive affects the initiation level. For a given shell, e.g., the 4.2 inch mortar shell, we can conclude from the sensitivity curves that the most sensitive was the Cyclotol filled, next was the TNT filled, and the least sensitive was the Composition B filled. For the 81 mm mortar shells the difference in sensitivity curves is very slight between TNT or Composition B, with the Composition B just slightly more sensitive.

This behavior of the 4.2 inch shell is unexpected since TNT is normally less sensitive than Composition B to all types of stimuli. Similarly Cyclotol 75/25 is normally less sensitive than Composition B. This is pointed out in numerous reports, two of which are Reference 10 and 11, where seven explosives have been subjected to eight sensitivity tests and graded. For each of the tests the results were arbitrarily expressed numerically in decreasing sensitivity order. See Table 19 listing these sensitivity evaluations. Note that TNT was subjected only to six sensitivity tests. Studying this table it is obvious that no two tests place the explosives in the same order. Because of these variations, a sum total assessment is made of the relative sensitivity of these seven explosives. For the explosives of interest in this investigation, you will note that Composition B is more sensitive than TNT and that Cyclotol falls in between these two.

If one selects the tests from Table 19 that most nearly simulate the stimuli found in the concrete fragment impact tests conducted on this program, it is the Susan and large scale impact tests. In the Susan test Cyclotol is more sensitive than Composition B and the opposite is true for the large scale drop tests. It is only the gap tests which find Cyclotol as the least sensitive of the explosives. Perhaps one reason that existing sensitivity data are not useful in helping us understand the behavior of the explosive items impacted by concrete fragments is that the explosives tested here are molten, while the literature data is for explosives at ambient temperature. Very little, if any, data exist on the sensitivity of molten explosives.

It has been assumed in this program's tests that the termodynamic state of the explosive is the same between tests. This may be questionable since the temperature of the explosive did vary from 77°C to 102°C (from 170°F to 216°F) between tests. The thermodynamic state is also important in that the manner in which the explosive deforms upon impact may determine the degree of viscous heating. This is especially important in secondary fragment impacts where it is conjectured that the extrusion of the explosive (from a ruptured shell or through the threaded top collar) could be another probable mechanism of initiation.

5. CONCLUSIONS

5.1 Phase I, ARRADCOM Test Series

Threshold impact velocities for initiation by concrete fragments were determined for the 4.2 inch mortar shell filled with Composition B, TNT, and Cyclotol and the Composition B filled 81 mm mortar shell.

An experimental model was developed which enables us to determine the impact sensitivity of an ammunition item by performing impact experiments at one size concrete fragment. This model was validated for seven shell/explosive configurations. The empirical model developed on this program will significantly reduce the number of tests required to characterize the sensitivity of an ammunition item to secondary fragments.

Because of the complexity of real shell geometries and lack of data and understanding of the sensitivity of molten explosives, it was not possible to develop a model that incorporates these parameters.

It was shown that sensitivity test data for solid explosives cannot be extended to order the impact sensitivity of molten explosives in shell casings.

5.2 Phase II, NSWC Test Series

The impact velocities at which brick wall fragments did not detonate the simulated munitions were determined. All data and film coverage collected were turned over to NSWC for their analysis.

6. RECOMMENDATIONS

An understanding of how the sensitivity of molten explosives compares with explosives at ambient temperature is required. Sensitivity data should be acquired for molten explosives, and for stimuli that simulate conditions that exist for the case of concrete fragment impact. The tests should be conducted at a single simple geometry, so that the test results represent basic behavior of the explosive.

Concurrently with experimental explosive sensitivity investigations, analyses should be conducted to determine how simple cylindrical shells filled with explosive deform under impact loads. This analytical work should then be extended to real shell geometries.

The analysis should be detailed enough to permit time-dependent calculations of the shell's deformation; volumetric change; stress, strain and strain rate; and the extrusion velocity and other flow velocities of the explosive.

The experimental determination of the explosive's sensitivity to impact and the results of the analyses of the shell deformation must be coupled for the development of a predictive model.

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Table 1

Accepter targets of secondary fragment impact tests

Target	Explosive Weight kg	(lb)	Shell Casing Weight kg	(lb)	Wall Thickness at max dia mm	(in)	Maximum Diameter mm	(in)	Max. Wall Thickness mm	(in)	Diameter at Max Wall Thickness mm	(in)	Explosive/ Case Weight E/C	Wall Thickness/ Max.Dia. t/D_{max}	Maximum Wall Thickness/ Diameter t_{max}/D
4.2 inch (M329A1) mortar shell	3.5	(8)	6.8	(15)	6.6	(0.26)	106.6	(4.195)	18.2	(0.718)	81.8	(3.22)	0.51	0.062	0.222
81 mm (M362A1) mortar shell	0.95	(2)	2.23	(5)	6.4 to 5.3 (0.25 to 0.21) At Groove 2.54	(0.10)	80.8	(3.182)	13.3	(0.525)	73.4	(2.89)	0.43	0.072 At Groove 0.031	0.181
120 mm (M356) cannon shell	3.6	(8)	18.2	(40)	15.1	(0.594)	120	(4.72)	25.4	(1.00)	120	(4.72)	0.20	0.126	0.212
155 mm (M107A1) howitzer shell	7.0	(15)	36.2	(80)	17.3	(0.68)	155	(6.1)	31.8	(1.25)	153.9	(6.06)	0.19	0.112	0.207

Table 2

Characteristics of concrete fragments

Fragment Size	Fragment Weight Kg	(lb)	Length/Diameter L/D	Actual Velocities used on this program's fragments m/sec	(ft/sec)	Estimated Maximum Velocity m/sec	(ft/sec)
Small	From 27 to 31	(From 60 to 68)	0.56	From 131 to 312	(From 430 to 1022)	341	(1120)
Medium Small	49 53	(105 116)	1.12	44 268	(160 880)	271	(890)
Medium	86 93	(190 205)	2.23	71 218	(234 715)	206	(675)
Long	172 179	(380 395)	4.47	55 138	(181 453)	148	(485)

Table 3

4.2 inch (M329A1) mortar shell "just filled" TNT with funnel in place test series data

(Reference 4)

Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Target 2
4.2S-1	05-10-77	14,479 kPa (2100 psi)	77°C (171°F)	27 kg (60 lb) L/D = 1/2	~273 m/sec (~896 ft/sec)		High order detonation	
4.2S-2	05-11-77	9,653 kPa (1400 psi)	80°C (176°F)	27 kg (60 lb) L/D = 1/2	242 m/sec (793 ft/sec)		No reaction: shell severely flattened	
4.2MS-1	05-12-77	14,479 kPa (2100 psi)	77°C (171°F)	52 kg (115 lb) L/D = 1	~236 m/sec (~774 ft/sec)		High order detonation	
4.2MS-2	05-13-77	9,997 kPa (1450 psi)	79°C (174°F)	51 kg (112 lb) L/D = 1	201 m/sec (659 ft/sec)		High order detonation	
4.2M-1	05-17-77	14,479 kPa (2100 psi)	81°C (178°F)	93 kg (205 lb) L/D = 2	160 m/sec (525 ft/sec)		No reaction: top of shell squeezed shut, funnel crushed	
4.2M-2	05-18-77	14,479 kPa (2100 psi)	79°C (174°F)	93 kg (205 lb) L/D = 2	168 m/sec (551 ft/sec)		Flash at impact	
4.2MS-3	05-19-77	5,516 kPa (800 psi)	79°C (174°F)	51 kg (112 lb) L/D = 1	123 m/sec (404 ft/sec)		High order detonation	

Table 3

4.2 inch (M329A1) mortar shell "just filled" TNT with funnel in place test series data

(contd)

Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2	Hit Location #1	Results: Target 1	Results: Target 2
4.2L-1	05-23-77	14,479 kPa (2100 psi)	79°C (174°F)	182 kg (400 lb) L/D = 2	143 m/sec (470 ft/sec)			High order detonation	
4.2M-3	05-24-77	8,274 kPa (1200 psi)	77°C (171°F)	86 kg (190 lb) L/D = 2	161 m/sec (528 ft/sec)			High order detonation	
4.2S-3	05-25-77	6,895 kPa (1000 psi)	74°C (165°F)	30 kg (66 lb) L/D = 1/2	226 m/sec (741 ft/sec)			High order detonation	
4.2MS-4	05-26-77	4,137 kPa (600 psi)	79°C (174°F)	52 kg (115 lb) L/D = 1	146 m/sec (480 ft/sec)			High order detonation	
4.2M-4	06-01-77	2,758 kPa (400 psi)	82°C (180°F)	91 kg (201 lb) L/D = 2	97 m/sec (318 ft/sec)			High order detonation	
4.2S-4	06-02-77	1,379 kPa (200 psi)	80°C (176°F)	30 kg (66 lb) L/D = 1/2	127 m/sec (417 ft/sec)			No reaction: shell squeezed flat in middle	

Table 3

4.2 inch (M329A1) mortar shell "just filled" TNT with funnel in place test series data

Present data

(contd)

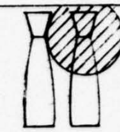
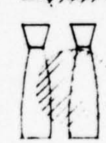
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Results Target 2
4.2-S-5	09-22-77	4,137 kPa (600 psi)	82°C (180°F)	27 kg (60 lb) L/D = 0.56	184 m/sec (604 ft/sec)		High order detonation Good hit	High order detonation
4.2-MS-5	09-23-77	1,724 kPa (250 psi)	79°C (174°F)	48 kg (105 lb) L/D = 1.12	113 m/sec (370 ft/sec)		No reaction: flattened and ripped open Good hit	No reaction: flattened and bowed
4.2-M-5	09-26-77	1,517 kPa (220 psi)	82°C (180°F)	93 kg (205 lb) L/D = 2.23	71 m/sec (234 ft/sec)		No reaction: top flattened and ripped open	No reaction: scratched No damage
4.2-S-6	09-27-77	2,758 kPa (400 psi)	82°C (180°F)	27 kg (60 lb) L/D = 0.56	150 m/sec (493 ft/sec)		High order detonation Good hit	No reaction: flattened
4.2-MS-6	09-28-77	2,068 kPa (300 psi)	83°C (181°F)	48 kg (105 lb) L/D = 1.12	105 m/sec (344 ft/sec)		No reaction: flattened and ripped open Low hit	No reaction: flattened
4.2-S-7	09-29-77	2,068 kPa (300 psi)	82°C (180°F)	29 kg (65 lb) L/D = 0.56	131 m/sec (430 ft/sec)		No reaction: bottom flattened Low hit	No reaction: scratched No damage
4.2-L-2	10-17-77	2,758 kPa (400 psi)	88°C (190°F)	177 kg (390 lb) L/D = 4.47	~62 m/sec (~205 ft/sec)		No reaction: flattened Good hit	No reaction: flattened

Table 3

4.2 inch (M329A1) mortar shell "just filled" TNT with funnel in place test series data

Present data

(concl)

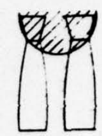
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
4.2-L-3	10-18-77	7,239 kPa (1050 psi)	88°C (190°F)	179 kg (395 lb) L/D = 4.47	103 m/sec (339 ft/sec)		No reaction: funnel sheared off High hit	No reaction: funnel sheared off
4.2-L-4	10-19-77	7,239 kPa (1050 psi)	88°C (190°F)	179 kg (395 lb) L/D = 4.47	106 m/sec (348 ft/sec)		No reaction: funnel caved in High hit	No reaction: funnel caved in

Table 4

81 mm (M362A1) mortar shell "just filled" TNT with funnel in place test series data

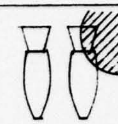
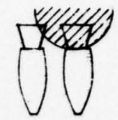
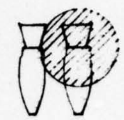
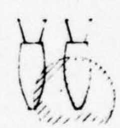
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Results Target 2
81-M-6	10-07-77	6,205 kPa (900 psi)	79°C (174°F)	91 kg (200 lb) L/D = 2.23	141 m/sec (464 ft/sec)		No reaction: slightly flattened high and to the right hit	No reaction: undamaged
81-M-7	10-10-77	6,205 kPa (900 psi)	77°C (170°F)	86 kg (190 lb) L/D = 2.23	144 m/sec (473 ft/sec)		No reaction: funnel sheared off-shell undamaged High hit	No reaction: funnel sheared off-shell undamaged
81-MS-5	10-12-77	12,411 kPa (1800 psi)	80°C (176°F)	48 kg (105 lb) L/D = 1.12	219 m/sec (718 ft/sec)		No reaction: smashed flat and split open Good hit	No reaction: undamaged
81-S-6	10-13-77	13,790 kPa (2000 psi)	~85°C (~185°F)	29 kg (65 lb) L/D = 0.56	~264 m/sec (~866 ft/sec)		No reaction: brushed shell lower right edge Low hit	No reaction: undamaged
81-S-7	10-14-77	13,790 kPa (2000 psi)	~85°C (~185°F)	29 kg (65 lb) L/D = 0.56	264 m/sec (866 ft/sec)		No reaction: smashed flat and ripped open Good hit	No reaction: top 1/3 flattened
81-MS-6	04-14-78	14,479 kPa (2100 psi)	81°C (177°F)	51 kg (113 lb) L/D = 1.12	~268 m/sec (~880 ft/sec)		High order detonation Good hit	No reaction: slightly flattened
81-L-5	05-09-78	14,479 kPa (2100 psi)	74°C (165°F)	177 kg (390 lb) L/D = 4.47	138 m/sec (453 ft/sec)		Low order reaction Low hit	No reaction: slightly damaged and scratched

Table 4

81 mm (M362A1) mortar shell "just filled" TNT with funnel in place test series data

(contd)

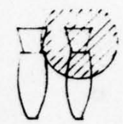
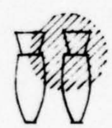
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
81-S-8	09-18-78	15,168 kPa (2200 psi)	85°C (185°F)	31 kg (68 lb) L/D = 0.56	301 m/sec (988 ft/sec)		No reaction: intact only scratched; high hit and to the left	No reaction: funnel smashed flat; shell-scratched
81-S-9	09-19-78	14,479 kPa (2100 psi)	80°C (176°F)	29 kg (65 lb) L/D = 0.56	312 m/sec (1022 ft/sec)		No reaction: shell in fragments Good hit	No reaction: shell in fragments
81-M-8	09-20-78	14,479 kPa (2100 psi)	80°C (176°F)	88 kg (195 lb) L/D = 2.23	214 m/sec (702 ft/sec)		No reaction: upper half of shell and funnel smashed flat Good hit	No reaction: shell and funnel dented
81-L-6	09-25-78	7,929 kPa (1150 psi)	79°C (175°F)	172 kg (380 lb) L/D = 4.47	112 m/sec (367 ft/sec)		No reaction: funnel only grazed High hit	No reaction: top of funnel damaged
81-MS-7	09-22-78	7,584 kPa (1100 psi)	83°C (181°F)	52 kg (115 lb) L/D = 1.12	196 m/sec (644 ft/sec)		High order detonation fragments Good hit	High order detonation fragments
81-M-9	09-26-78	5,516 kPa (800 psi)	85°C (185°F)	86 kg (190 lb) L/D = 2.23	141 m/sec (464 ft/sec)		No reaction: smashed into fragments Good hit	No reaction: smashed into fragments
81-MS-8	10-05-78	5,171 kPa (750 psi)	81°C (177°F)	52 kg (114 lb) L/D = 1.12	181 m/sec (595 ft/sec)		No reaction: smashed into fragments Good hit	No reaction: smashed into fragments

Table 4

81 mm (M362A1) mortar shell "just filled" TNT with funnel in place test series data

(concl)

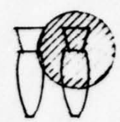
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
81-L-7	10-06-78	6,205 kPa (900 psi)	$85^{\circ}C$ ($185^{\circ}F$)	179 kg (395 lb) L/D = 4.47	104 m/sec (340 ft/sec)		No reaction: intact high hit and to the left	No reaction: funnel dented shell intact
81-L-8	10-09-78	6,205 kPa (900 psi)	$80^{\circ}C$ ($176^{\circ}F$)	172 kg (380 lb) L/D = 4.47	109 m/sec (356 ft/sec)		No reaction: smashed into fragments Good hit	No reaction: shell intact funnel missing

Table 5

4.2 inch (M329A1) mortar shell "just filled" Composition B with funnel in place test series data

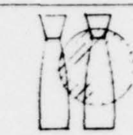
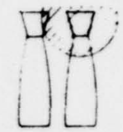
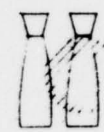
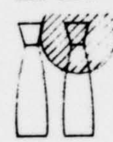
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
4.2-L-5	10-24-77	7,239 kPa (1050 psi)	86°C (186°F)	179 kg (395 lb) L/D = 4.47	105 m/sec (346 ft/sec)		No reaction: flattened, nose and base piece torn loose Good hit	No reaction: flattened; nose and base piece torn loose
4.2-M-6	10-25-77	5,171 kPa (750 psi)	83°C (182°F)	91 kg (200 lb) L/D = 2.23	122 m/sec (399 ft/sec)		No reaction: mouth caved in and flattened Good hit	No reaction: funnel crushed shell scratched
4.2-MS-7	10-26-77	4,826 kPa (700 psi)	89°C (193°F)	52 kg (115 lb) L/D = 1.12	148 m/sec (485 ft/sec)		Low order reaction: split open and bulged out Good hit	No reaction: top nicked and shell scratched
4.2-L-6	10-27-77	10,342 kPa (1500 psi)	84°C (184°F)	179 kg (395 lb) L/D = 4.47	~122 m/sec (~400 ft/sec)		High order reaction: small fragments Good hit	Low order reaction: flattened and bowed nose and base torn loose
4.2-M-7	10-28-77	8,963 kPa (1300 psi)	86°C (187°F)	91 kg (200 lb) L/D = 2.23	157 m/sec (516 ft/sec)		No reaction: top half flattened Good hit	Used only one target
4.2-S-8	10-31-77	3,792 kPa (550 psi)	84°C (183°F)	29 kg (65 lb) L/D = 0.56	161 m/sec (527 ft/sec)		No reaction: slightly dented and flattened	No reaction: top half flattened; funnel missing Good hit
4.2-S-9	04-05-78	10,342 kPa (1500 psi)	86°C (186°F)	29 kg (65 lb) L/D = 0.56	256 m/sec (839 ft/sec)		High order detonation; split wide open Good hit	Low order reaction; thrown out of area; base torn loose

Table 5
4.2 inch (M329A1) mortar shell "just filled" Composition B with funnel in place test series data

(concl)

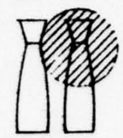
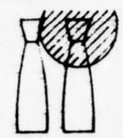
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Results Target 2
4.2-MS-8	04-07-78	3,447 kPa (500 psi)	83°C (182°F)	52 kg (115 lb) L/D = 1.12	135 m/sec (442 ft/sec)		No reaction: smashed flat Good hit	No reaction: dented and flattened
4.2-MS-9	04-10-78	7,584 kPa (1100 psi)	82°C (179°F)	52 kg (115 lb) L/D = 1.12	204 m/sec (668 ft/sec)		No reaction: flattened and split open Good hit	No reaction: caved in
4.2-M-8	04-11-78	14,479 kPa (2100 psi)	82°C (180°F)	93 kg (204 lb) L/D = 2.23	~218 m/sec (~715 ft/sec)		No reaction: mouth crushed and bulged High good hit	No reaction: top dented
4.2-L-7	04-12-78	5,860 kPa (850 psi)	84°C (184°F)	177 kg (390 lb) L/D = 4.47	92 m/sec (303 ft/sec)		No reaction: top edge grazed High hit	No reaction: funnel smashed flat shell intact

Table 6

4.2 inch (M329A1) mortar shell "just filled" Cyclotol 75/25 with funnel in place test series data

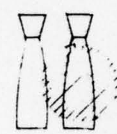
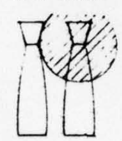
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
4.2-MS-10	10-10-78	5,171 kPa (750 psi)	96°C (204°F)	52 kg (115 lb) L/D = 1.12	178 m/sec (583 ft/sec)		High order detonation: fragments witness plate in pieces Good hit	High order detonation: fragments
4.2-M-9	10-11-78	5,516 kPa (800 psi)	93°C (200°F)	88 kg (195 lb) L/D = 2.23	146 m/sec (478 ft/sec)		High order detonation: fragments witness plate bowed Good hit	High order detonation: fragments
4.2-M-10	10-12-78	2,068 kPa (300 psi)	97°C (206°F)	91 kg (200 lb) L/D = 2.23	~84 m/sec (~275 ft/sec)		No reaction: flattened Good hit	No reaction: flattened and base torn loose
4.2-MS-11	10-13-78	1,379 kPa (200 psi)	88°C (190°F)	52 kg (115 lb) L/D = 1.12	~101 m/sec (~330 ft/sec)		High order detonation: fragments witness plate bowed Good hit	High order detonation: fragments
4.2-S-10	10-16-78	1,724 kPa (250 psi)	88°C (190°F)	29 kg (65 lb) L/D = 0.56	~134 m/sec (~440 ft/sec)		No reaction: split open and smashed Good hit	No reaction: dented on side
4.2-S-11	10-17-78	6,205 kPa (900 psi)	98°C (208°F)	29 kg (65 lb) L/D = 0.56	228 m/sec (749 ft/sec)		No reaction: flattened Good hit	No reaction: caved in and folded over
4.2-L-8	10-18-78	4,826 kPa (700 psi)	99°C (211°F)	177 kg (390 lb) L/D = 4.47	95 m/sec (313 ft/sec)		High order detonation: fragments Good hit	High order detonation: fragments

Table 6

4.2 inch (M329A1) mortar shell "just filled" Cyclotol 75/25 with funnel in place test series data

(contd)

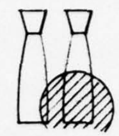
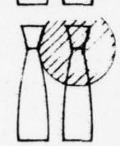
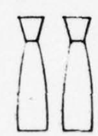
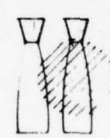
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
4.2-L-9	10-19-78	2,068 kPa (300 psi)	102°C (216°F)	175 kg (385 lb) L/D = 4.47	. 66 m/sec (217 ft/sec)		No reaction: lower half dented Low hit	No reaction: lower half dented
4.2-L-10	10-20-78	1,379 kPa (200 psi)	96°C (204°F)	175 kg (385 lb) L/D = 4.47	55 m/sec (181 ft/sec)		No reaction: lower half dented-witness plate 15.24m (50 ft) up range Low hit	No reaction: lower portion dented
4.2-MS-12	10-23-78	1,172 kPa (170 psi)	88°C (190°F)	53 kg (116 lb) L/D = 1.12	~84 m/sec (~275 ft/sec)		High order detonation: fragments Good hit	No reaction: dented and scratched
4.2-M-11	10-24-78	3,103 kPa (450 psi)	88°C (190°F)	88 kg (195 lb) L/D = 2.23	105 m/sec (345 ft/sec)		Low order reaction flattened and base torn loose Good hit	Low order reaction; flattened and ripped open, base plate torn loose
4.2-S-12	10-24-78	9,997 kPa (1450 psi)	88°C (191°F)	29 kg (65 lb) L/D = 0.56	262 m/sec (858 ft/sec)		High order detonation: fragments Good hit	Low order reaction; flattened and top torn loose
4.2-MS-13	10-26-78	689 kPa (100 psi)	82°C (180°F)	52 kg (115 lb) L/D = 1.12	49 m/sec (160 ft/sec)		No reaction: fragment tumbled into shell-scratched	No reaction: scratched
4.2-L-11	10-27-78	2,068 kPa (300 psi)	87°C (188°F)	175 kg (385 lb) L/D = 4.47	60 m/sec (196 ft/sec)		No reaction: flattened Good hit	No reaction: flattened

Table 6

4.2 inch (M329A1) mortar shell "just filled" Cyclotol 75/25 with funnel in place test series data

(concl)

Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Results Target 2
4.2-MS-14	10-30-78	689 kPa (100 psi)	94°C (202°F)	52 kg (115 lb) L/D = 1.12	59 m/sec (193 ft/sec)		No reaction: flattened Good hit	No reaction: slightly flattened and scratched

Table 7

81 mm (M362A1) mortar shell "just filled" Composition B with funnel in place test series data

(Reference 4)

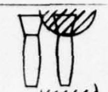
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Results Target 2
81S-1	8-09-76	11,135 Kpa (1615 psi)	44°C (111°F)	34 kg (75 lb) L/D = 1/2	~260 m/sec (~853 ft/sec)		No reaction: funnel sheared off, no damage to shell	No reaction: no damage to funnel or shell
81S-2	8-11-76	13,790 kPa (2000 psi)	44°C (111°F)	33 kg (73 lb) L/D = 1/2	284 m/sec (932 ft/sec)		No reaction: funnel sheared off, no damage to shell	No reaction: funnel sheared off, no damage to shell
81S-3	8-13-76	13,790 kPa (2000 psi)	64°C (147°F)	34 kg (75 lb) L/D = 1/2	262 m/sec (858 ft/sec)		No reaction: only funnel and small metal fragments recovered	No reaction: small dent on shell, no damage to funnel
81S-4	9-01-76	14,479 kPa (2100 psi)	71-75°C (160-167°F)	34 kg (75 lb) L/D = 1/2	263 m/sec (864 ft/sec)		No reaction: bottom crushed	No reaction: bottom bent
81MS-1	9-03-76	13,962 kPa (2025 psi)	78-80°C (172-176°F)	52 kg (115 lb) L/D = 1	234 m/sec (768 ft/sec)		No reaction: shell severely crushed	No reaction: no damage to shell or funnel
81M-1	9-08-76	13,927 kPa (2020 psi)	76-78°C (168-172°F)	93 kg (205 lb) L/D = 2	186 m/sec (611 ft/sec)		Low order reaction	High order detonation
81MS-2	9-13-76	14,651 kPa (2125 psi)	81-88°C (177-190°F)	54 kg (120 lb) L/D = 1	214 m/sec (703 ft/sec)		No reaction: top of shell squeezed shut	No reaction: funnel destroyed, no shell damage
81M-2	9-14-76	8,618 kPa (1250 psi)	76°C (168°F)	95 kg (210 lb) L/D = 2	163 m/sec (535 ft/sec)		High order detonation	Possible sympathetic high order detonation
81S-5	9-15-76	14,341 kPa (2080 psi)	75-76°C (166-168°F)	32 kg (70 lb) L/D = 1/2	276 m/sec (906 ft/sec)		High order detonation	No reaction: funnel destroyed, top of shell crushed
81M-3	9-16-76	4,826 kPa (700 psi)	77-82°C (170-179°F)	93 kg (205 lb) L/D = 2	134 m/sec (440 ft/sec)		No reaction: shell severely crushed	No reaction: no shell or funnel damage

Table 7

81 mm (M362A1) mortar shell "just filled" Compostion B with funnel in place test series data

(concl)

Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Target 2
81MS-3	9-17-76	13,603 kPa (1973 psi)	68-83°C (155-181°F)	52 kg (115 lb) L/D = 1	248 m/sec (813 ft/sec)		High order detonation	No reaction: no shell damage, funnel bent at neck
81-L-1	9-21-76	14,582 kPa (2115 psi)	78-79°C (173-175°F)	181 kg (400 lb) L/D = 4	137 m/sec (449 ft/sec)		No reaction: funnel crushed	No reaction: funnel dented
81M-4	9-22-76	6,205 kPa (900 psi)	82°C (179°F)	93 kg (205 lb) L/D = 2	133 m/sec (435 ft/sec)		High order detonation	No reaction: no damage to shell or funnel
81MS-4	9-23-76	13,031 kPa (1890 psi)	78-79°C (172-174°F)	52 kg (115 lb) L/D = 1	232 m/sec (760 ft/sec)		No reaction: funnel and top of shell crushed	No reaction: funnel dented
81M-5	10-14-76	4,268 kPa (619 psi)	67-72°C (152-162°F)	91 kg (200 lb) L/D = 2	109 m/sec (358 ft/sec)		No reaction: funnel flattened, shell squeezed shut	No reaction: no damage to shell
81L-2	10-15-76	15,237 kPa (2210 psi)	77°C (171°F)	184 kg (405 lb) L/D = 4	~117 m/sec (~383 ft/sec)		High order detonation; funnel only slightly dented	No reaction: small scratch on shell
81L-3	10-18-76	8,287 kPa (1201 psi)	74-79°C (166-175°F)	177 kg (390 lb) L/D = 4	109 m/sec (359 ft/sec)		No reaction: funnel and shell crushed	No reaction: no damage
81L-4	4-20-77	13,445 kPa (1950 psi)	70°C (158°F)	181 kg (400 lb) L/D = 4	139 m/sec (457 ft/sec)		No reaction: funnel and shell slightly damaged	No reaction: no damage

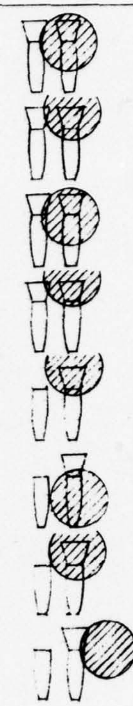


Table 8

120 mm (T15E2, M356) cannon projectile "just filled" Composition B with funnel in place test series data

(Reference 4)

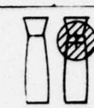
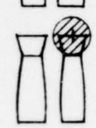
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
120S-1	9-24-76	14,548 kPa (2110 psi)	81°C (178°F)	32 kg (71 lb) L/D = 1/2	269 m/sec (882 ft/sec)		No reaction: top of shell and funnel crushed	No reaction: no damage to shell or funnel
120MS-1	9-28-76	14,755 kPa (2140 psi)	77-78°C (171-172°F)	51 kg (112 lb) L/D = 1	243 m/sec (797 ft/sec)		High order detonation	No reaction: no shell or funnel damage
120L-1	9-29-76	16,285 kPa (2362 psi)	77-81°C (171-178°F)	184 kg (406 lb) L/D = 4	149 m/sec (489 ft/sec)		No reaction: funnel destroyed, top of shell squeezed shut	No reaction: funnel broke off, *scratches on shell*
120S-2	9-30-76	16,706 kPa (2423 psi)	81°C (178°F)	34 kg (75 lb) L/D = 1/2	301 m/sec (988 ft/sec)		Burning reaction: shell broke in half	No reaction: funnel dented, no shell damage
120M-1	10-04-76	14,169 kPa (2055 psi)	72-75°C (162-167°F)	93 kg (205 lb) L/D = 2	~176 m/sec (~576 ft/sec)		No reaction: funnel destroyed, top of shell squeezed shut	No reaction: funnel dented, no damage to shell
120MS-2	10-05-76	6,895 kPa (1000 psi)	72-78°C (162-172°F)	52 kg (115 lb) L/D = 1	173 m/sec (568 ft/sec)		No reaction: funnel sheared off, no damage to shell	No reaction: no damage to funnel or shell
120MS-3	10-06-76	6,895 kPa (1000 psi)	74-78°C (165-172°F)	52 kg (115 lb) L/D = 1	182 m/sec (596 ft/sec)		No reaction: funnel broke off, shell slightly dented	No reaction: no damage to funnel, scratches on side of shell

Table 8

120 mm (T15E2, M356) cannon projectile "just filled" Composition B with funnel in place test series data

(contd)

Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
120M-2	10-07-76	14,893 kPa (2160 psi)	73°C (163°F)	95 kg (209 lb) L/D = 2	180 m/sec (591 ft/sec)		No reaction: funnel broke off, shell slightly dented	No reaction: no damage to funnel or shell
120MS-4	10-11-76	11,307 kPa (1640 psi)	73°C (163°F)	52 kg (115 lb) L/D = 1	220 m/sec (721 ft/sec)		No reaction: funnel destroyed, top of shell squeezed shut	No reaction: funnel destroyed, top of shell scratched
120M-3	10-12-76	15,168 kPa (2200 psi)	78-79°C (172-174°F)	93 kg (205 lb) L/D = 2	199 m/sec (652 ft/sec)		No reaction: funnel destroyed, top of shell squeezed shut	No reaction: no damage to funnel or shell
120L-2	10-13-76	15,168 kPa (2200 psi)	79°C (174°F)	184 kg (406 lb) L/D = 4	~109 m/sec (~358 ft/sec)		Burning reaction: funnel destroyed, shell broke in half, bottom left intact	
120L-3	10-20-76	11,101 kPa (1610 psi)	80°C (176°F)	181 kg (400 lb) L/D = 4	~88 m/sec (~288 ft/sec)		No reaction: funnel destroyed, top of shell squeezed	
120M-4	10-22-76	15,506 kPa (2249 psi)	83°C (181°F)	89 kg (197 lb) L/D = 2	182 m/sec (596 ft/sec)		No reaction: funnel destroyed, shell slightly dented	
120S-3	10-26-76	11,032 kPa (1600 psi)	79°C (174°F)	34 kg (75 lb) L/D = 1/2	~244 m/sec (~800 ft/sec)		Burning reaction: no shell damage, wooden stand charred	

Table 8

120 mm (T15E2, M356) cannon projectile "just filled" Composition B with funnel in place test series data

(concl)

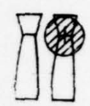
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Results Target 2
120S-4	10-29-76	6,895 kPa (100 psi)	80°C (176°F)	33 kg (73 lb) L/D = 1/2	178 m/sec (585 ft/sec)		No damage, gun misaligned (not shown in Fig. 17)	
120S-5	11-02-76	6,895 kPa (1000 psi)	80°C (176°F)	34 kg (75 lb) L/D = 1/2	~178 m/sec (~585 ft/sec)		No reaction: shell dented ~ 2.54 cm (~1 in.) deep, funnel broken off	
120S-6	05-04-77	12,631 kPa (1832 psi)	81°C (178°F)	30 kg (66 lb) L/D = 1/2	~207 m/sec (~679 ft/sec)		No reaction: funnel sheared off, no damage to shell	No reaction: no damage to funnel or shell
120L-4	05-05-77	12,548 kPa (1820 psi)	77°C (171°F)	184 kg (405 lb) L/D = 4	~129 m/sec (~422 ft/sec)		No reaction: funnel destroyed, shell squeezed shut	No reaction: funnel destroyed, no shell damage

Table 9

155 mm (M107A1) howitzer shell "just filled" Composition B with funnel in place test series data

(Reference 4)

Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location 2 1	Results Target 1	Results Target 2
155S-1	8-18-76	12135 kPa (1760 psi)	80-83°C (176-181°F)	34 kg (75 lb) L/D=1/2	244 m/sec (802 ft/sec)		High order detonation	Low order reaction
155S-2	8-19-76	8446 kPa (1225 psi)	81-83°C (178-181°F)	34 kg (75 lb) L/D=1/2	216 m/sec (708 ft/sec)		No reaction: Funnel sheared off, no shell damage	No reaction: no funnel or shell damage
155M-1	8-20-76	8274 kPa (1200 psi)	85-88°C (185-190°F)	93 kg (205 lb) L/D=2	~161 m/sec (~529 ft/sec)		High order detonation	Low order reaction
155M-2	8-24-76	600 kPa (870 psi)	84-87°C (183-189°F)	95 kg (210 lb) L/D=2	~133 m/sec (~435 ft/sec)		Low order reaction	No reaction; scratches on shell
155L-1	8-26-76	14203 kPa (2060 psi)	77-86 C (171-187°F)	186 kg (410 lb) L/D=4	145 m/sec (475 ft/sec)		No reaction: funnel sheared off, no shell damage	No reaction: no damage to shell or funnel
155L-2	8-30-76	13996 kPa (2030 psi)	77-82°C (171-180°F)	186 kg (410 lb) L/D=4	145 m/sec (476 ft/sec)		No reaction: top of shell squeezed shut	No reaction: top of shell squeezed shut

Table 10

155 mm howitzer shell "just filled" Composition B test series data

(Reference 3)

Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
JS-1	10-11-74	13,790 kPa (2000 psi)	82°C (180°F)	32 kg (70 lb)	249 m/sec (818 ft/sec)		No reaction: ~0.32 cm (~1/8 in.) deep smooth dent, ~8 cm (~3 in.) above rotating band	No reaction: scratches on the surface, ~8 cm (~3 in.) above rotating band
JM-1	10-17-74	13,790 kPa (2000 psi)	82°C (180°F)	84 kg (185 lb)	224 m/sec (736 ft/sec)		Low order reaction, large fragment, approximately into 3 equal pieces posttest, slight bend on witness plate immediately under	No reaction: scratches on surface, ~23 cm (~9 in.) below the top
JL-1	10-26-74	13,790 kPa (2000 psi)	82°C (180°F)	170 kg (375 lb)	154 m/sec (504 ft/sec)		Flash of black smoke, possible smouldering, top squeezed	Not applicable
JS-2	5-02-75	15,518 kPa (2250 psi)	93°C (200°F)	23 kg (50 lb)	~335 m/sec (~1100 ft/sec)		High order detonation, small fragments posttest, severe damage on witness plate immediately under	High order detonation, small fragments posttest, not as severe damage on witness plate immediately under
JS-3	5-05-75	15,168 kPa (2200 psi)	91°C (195°F)	23 kg (50 lb)	~335 m/sec (~1100 ft/sec)		High order detonation, small fragments posttest, clear imprint of base on witness plate immediately under, severe bending of witness plate immediately under	Low order reaction, large fragments, but less than 30 cm (12 in.) long, posttest, slight imprint of base on witness plate immediately under

Table 10

155 mm howitzer shell "just filled" Composition B test series data

(contd)

Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
JM-2	5-06-75	14,478 kPa (2100 psi)	93°C (200°F)	84 kg (185 lb)	~219 m/sec (~720 ft/sec)		High order detonation, small fragments posttest, clear imprint of base on witness plate, bending of witness plate immediately under	Low order reaction, large pieces of fragments, whole length of the target, scratches ~20 cm (~8 in.) below top
JL-2	5-29-75	14,478 kPa (2100 psi)	93°C (200°F)	170 kg (375 lb)	140 m/sec (460 ft/sec)		No reaction: sharp and deep dent, ~23 cm (~9 in.) below top	No reaction: scratches ~23 cm (~9 in.) below top
JM-3	5-30-75	6,549 kPa (950 psi)	96°C (205°F)	84 kg (185 lb)	166 m/sec (546 ft/sec)		Deflagaration, target fragmented into 3 equal pieces, unburnt Comp B in base posttest, bending of witness plate immediately under	No reaction; unburnt Comp B in shell, scratches on surface, ~18 cm (~7 in.) below top
JL-3	6-03-75	8,963 kPa (1300 psi)	96°C (205°F)	170 kg (375 lb)	132 m/sec (432 ft/sec)		No reaction: dent and slight squeezing on upper 1/4 of target	No reaction: no damage
JM-4	10-22-75	6,549 kPa (950 psi)	93°C (200°F)	84 kg (185 lb)	141 m/sec (465 ft/sec)		No reaction: smooth dent, ~15 cm (~6 in.) above rotating band	No reaction: scratches on surface, ~15 cm (~6 in.) above rotating band
JM-5	10-23-75	6,549 kPa (950 psi)	93°C (200°F)	84 kg (185 lb)	144 m/sec (472 ft/sec)		No reaction: slight and smooth dent, ~18 cm (~7 in.) above rotating band	No reaction: slight and smooth dent, ~18 cm (~7 in.) above rotating band

Table 10

155 mm howitzer shell "just filled" Composition B test series data

(concl)

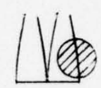
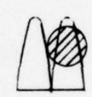
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
JM-6	10-24-75	6,549 kPa (950 psi)	93°C (200°F)	84 kg (185 lb)	150 m/sec (490 ft/sec)		No reaction: slight dent, ~13 cm (~5 in.) above rotating band	No reaction: scratches on surface, ~13 cm (~5 in.) above rotating band
JS-4	10-27-75	8,790 kPa (1275 psi)	92°C (197°F)	24 kg (52 lb)	244 m/sec (800 ft/sec)		No reaction: ~1 cm (~1/2 in.) deep smooth dent, ~11 cm (~4-1/2 in.) above rotating band	No reaction: ~1 cm (~1/2 in.) deep smooth dent, ~11 cm (~4-1/2 in.) above rotating band
JS-5	10-28-75	13,789 kPa (2000 psi)	92°C (197°F)	24 kg (52 lb)	274 m/sec (900 ft/sec)		No reaction: slight, smooth dent around rotating band	No reaction: scratches on surface around rotating band
JS-6	10-30-75	13,789 kPa (2000 psi)	89°C (193°F)	24 kg (52 lb)	265 m/sec (869 ft/sec)		No reaction: deep sharp dent in middle, slight bending of whole target	No reaction: scratches on surface around rotating band
JS-7	11-03-75	15,513 kPa (2250 psi)	86°C (187°F)	24 kg (52 lb)	325 m/sec (1065 ft/sec)		No reaction: glancing hit, scratches on surface, ~15 cm (~6 in.) above rotating band	No reaction: no damage
JL-4	11-04-75	15,513 kPa (2250 psi)	86°C (187°F)	170 kg (375 lb)	159 m/sec (520 ft/sec)		No reaction: shallow dent ~18 cm (~7 in.) below top	No reaction: scratches on surface ~18 cm (~7 in.) below top
JL-5	11-05-75	15,513 kPa (2250 psi)	86°C (187°F)	170 kg (375 lb)	143 m/sec (470 ft/sec)		No reaction: smooth and deep dent, ~1 cm (~1/2 in.) deep, ~18 cm (~7 in.) below top	No reaction: scratches

Table 11

Secondary fragment velocity/mass data

Fragment Weight kg	(lb)	Boundary Velocity m/sec	(ft/sec)	Momentum N-sec	(slug-ft/sec)	Kinetic Energy J x 10^6	(ft-lb x 10^6)
81 mm (M362A1) mortar shell - TNT filled							
23	(50)	299	(980)	6877	(1522)	1.028	(0.746)
29	(65)	259	(850)	7511	(1716)	0.973	(0.729)
45	(100)	198	(650)	8910	(2019)	0.882	(0.656)
91	(200)	137	(450)	12467	(2795)	0.854	(0.629)
136	(300)	119	(389)	16184	(3624)	0.963	(0.705)
181	(400)	110	(362)	19910	(4497)	1.095	(0.814)
81 mm (M362A1) mortar shell - Composition B filled (Reference 4)							
23	(50)	262	(860)	6026	(1335)	0.789	(0.574)
29	(65)	238	(780)	6902	(1575)	0.821	(0.614)
45	(100)	192	(630)	8640	(1957)	0.829	(0.616)
91	(200)	128	(420)	11648	(2609)	0.745	(0.548)
136	(300)	114	(375)	15504	(3494)	0.884	(0.655)
181	(400)	110	(360)	19910	(4472)	1.095	(0.805)

Table 12

Secondary Fragment Velocity/Mass Data

Fragment Weight kg	(lb)	Boundary Velocity m/sec	(ft/sec)	Momentum N-sec	(slug-ft/sec)	Kinetic Energy J x 10^6	(ft-lb x 10^6)
4.2 inch (M329A1) mortar shell - TNT filled							
23	(50)	144	(472)	3312	(733)	0.238	(0.173)
29	(65)	130	(425)	3770	(858)	0.245	(0.182)
45	(100)	110	(360)	4950	(1118)	0.272	(0.201)
91	(200)	84	(275)	7644	(1708)	0.321	(0.235)
136	(300)	74	(242)	10064	(2255)	0.372	(0.273)
181	(400)	69	(225)	12489	(2795)	0.431	(0.314)
4.2 inch (M329A1) mortar shell - Composition B filled							
23	(50)	178	(585)	4094	(908)	0.364	(0.266)
29	(65)	166	(545)	4814	(1100)	0.400	(0.300)
45	(100)	144	(472)	6480	(1466)	0.467	(0.346)
91	(200)	113	(372)	10283	(2311)	0.581	(0.430)
136	(300)	99	(326)	13464	(3037)	0.666	(0.495)
181	(400)	91	(300)	16471	(3727)	0.749	(0.559)
4.2 inch (M329A1) mortar shell - Cyclotol 75/25 filled							
23	(50)	119	(390)	2737	(606)	0.163	(0.118)
29	(65)	102	(335)	2958	(676)	0.151	(0.113)
45	(100)	84	(275)	3780	(854)	0.159	(0.117)
91	(200)	69	(228)	6279	(1416)	0.217	(0.161)
136	(300)	64	(210)	8704	(1957)	0.279	(0.205)
181	(400)	61	(200)	11041	(2484)	0.337	(0.248)

Table 13

Secondary fragment velocity/mass data
(Reference 4)

Fragment Weight		Boundary Velocity		Momentum		Kinetic Energy	
kg	(lb)	m/sec	(ft/sec)	N-sec	(slug-ft/sec)	J x 10^6	(ft-lb x 10^6)
120 mm (M356) cannon shell - Composition B filled							
23	(50)	238	(780)	5474	(1211)	0.651	(0.472)
29	(65)	227	(745)	6583	(1504)	0.747	(0.560)
45	(100)	210	(690)	9450	(2143)	0.992	(0.739)
91	(200)	162	(530)	14742	(3292)	1.194	(0.872)
136	(300)	126	(415)	17136	(3866)	1.080	(0.802)
181	(400)	101	(330)	18281	(4099)	0.923	(0.676)

Table 14

Secondary fragment velocity/mass data
(References 3 and 4)

Fragment Weight kg	(lb)	Boundary Velocity m/sec	(ft/sec)	Momentum N-sec	(slug-ft/sec)	Kinetic Energy J x 10^6	(ft-lb x 10^6)
155 mm (M107A1) howitzer shell - Composition B filled							
23	(50)	255	(835)	5865	(1297)	0.748	(0.541)
29	(65)	232	(760)	6728	(1534)	0.780	(0.583)
45	(100)	189	(620)	8505	(1925)	0.804	(0.597)
91	(200)	126	(415)	11466	(2578)	0.722	(0.535)
136	(300)	110	(360)	14960	(3354)	0.823	(0.604)
181	(400)	107	(350)	19367	(4348)	1.036	(0.761)

Table 15
Variations in velocities between
derived and empirical power equations
4.2 inch (M329A1) mortar shell-TNT filled

Fragment Weight		Experimental Boundary Velocity		Velocity from Empirical Equation		Velocity from Derived Equation	
kg	(lb)	m/sec	(ft/sec)	m/sec	(ft/sec)	m/sec	(ft/sec)
23	(50)	144	(472)	142	(466)	142	(466)
29	(65)	130	(425)	132	(433)	131	(430)
45	(100)	110	(360)	114	(374)	112	(367)
91	(200)	84	(274)	90	(295)	87	(285)
136	(300)	74	(242)	79	(259)	75	(246)
181	(400)	69	(225)	72	(236)	68	(223)

Table 16

Comparison of the derived and empirical power equation for seven configurations

Configuration	Derived Equation	Empirical Equation
4.2 inch - Cyclotol 75/25	$V = 300\ W^{-0.31}$	$V = 325\ W^{-0.32}$
4.2 inch - TNT	$V = 440\ W^{-0.36}$	$V = 400\ W^{-0.33}$
4.2 inch - Composition B	$V = 500\ W^{-0.33}$	$V = 540\ W^{-0.35}$
81 mm - Composition B	$V = 1060\ W^{-0.45}$	$V = 1035\ W^{-0.44}$
81 mm - TNT	$V = 1350\ W^{-0.49}$	$V = 1500\ W^{-0.52}$
120 mm - Composition B	$V = 900\ W^{-0.40}$	$V = 850\ W^{-0.41}$
155 mm - Composition B	$V = 1050\ W^{-0.45}$	$V = 960\ W^{-0.43}$

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Table 17

Variations in velocities between derived and empirical power equations

Fragment Weight kg	(lb)	Experimental Boundary Velocity m/sec	(ft/sec)	Velocity from Empirical Equation m/sec	(ft/sec)	Velocity from Derived Equation m/sec	(ft/sec)
4.2 inch (M329A1) mortar shell - Cyclotol filled							
23	(50)	119	(390)	119	(390)	113	(371)
29	(65)	102	(335)	111	(364)	106	(348)
45	(100)	84	(276)	96	(315)	92	(302)
91	(200)	69	(226)	77	(253)	74	(243)
136	(300)	64	(210)	67	(220)	65	(213)
181	(400)	61	(200)	62	(203)	60	(197)
4.2 inch (M329A1) mortar shell - Composition B filled							
23	(50)	178	(584)	180	(591)	178	(584)
29	(65)	166	(545)	166	(545)	165	(541)
45	(100)	144	(472)	142	(466)	142	(466)
91	(200)	113	(371)	111	(364)	113	(371)
136	(300)	99	(325)	97	(318)	99	(325)
181	(400)	91	(299)	88	(289)	90	(295)
81 mm (362A1) mortar shell - TNT filled							
23	(50)	299	(981)	294	(965)	290	(951)
29	(65)	259	(850)	260	(853)	259	(850)
45	(100)	198	(650)	207	(679)	209	(686)
91	(200)	137	(449)	144	(472)	148	(486)
136	(300)	119	(390)	117	(384)	122	(400)
181	(400)	110	(361)	100	(328)	106	(348)

Table 17

Variations in velocities between derived and empirical power equations

(concl)

Fragment Weight kg	(lb)	Experimental Boundary Velocity m/sec	(ft/sec)	Velocity from Empirical Equation m/sec	(ft/sec)	Velocity from Derived Equation m/sec	(ft/sec)
81 mm (M362A1) mortar shell - Composition B filled							
23	(50)	262	(860)	260	(853)	259	(850)
29	(65)	238	(781)	235	(771)	233	(764)
45	(100)	192	(630)	194	(636)	191	(627)
91	(200)	128	(420)	142	(466)	139	(456)
136	(300)	114	(374)	119	(390)	116	(381)
181	(400)	110	(361)	105	(344)	102	(335)
120 mm M356 (T15E2) cannon shell - Composition B filled							
23	(50)	238	(780)	235	(771)	257	(843)
29	(65)	227	(745)	214	(702)	234	(768)
45	(100)	210	(689)	178	(584)	196	(643)
91	(200)	162	(531)	134	(440)	148	(486)
136	(300)	126	(413)	113	(371)	126	(413)
181	(400)	101	(331)	101	(331)	113	(371)
155 mm (M107A1) howitzer shell - Composition B filled							
23	(50)	255	(837)	249	(817)	256	(840)
29	(65)	232	(761)	226	(741)	231	(758)
45	(100)	189	(620)	187	(614)	189	(620)
91	(200)	126	(413)	138	(453)	138	(453)
136	(300)	110	(361)	116	(381)	115	(377)
181	(400)	107	(351)	103	(338)	101	(331)

Table 18

Relationship between the lowest impact velocity for initiation and t/D ratio for various shells

Target Shell	t/D max	$V_{Composition\ B}$ m/sec	$V_{Composition\ B}$ (ft/sec)	V_{TNT} m/sec	V_{TNT} (ft/sec)
4.2 inch (M329A1) mortar shell	0.062	122	(400)	131	(430)
81 mm (M362A1) mortar shell	0.072	131	(430)	137	(450)
155 mm (M107A1) howitzer shell	0.112	137	(450)	—	—
120 mm (M356) cannon shell	0.126	244	(800)	—	—

Table 19
Summary evaluation of sensitivity tests
(Reference 9 and 10)

Explosive	Drop Weight Test	Small Scale Gap	Large Scale Gap	Riffle Bullet Test	Large Scale Drop *	Skid Test *	Susan Test	Impact Test 5 kg Wt Type 12 Tooling	Sum	Overall Sensitivity for explosives of interest in this Investigation
PBX-9010	1	1	2	2	2	1	2	2	10	1
Cyclotol 75/25	2	7	7	6	5	5	3	3	28	4
Octol 75/25	3	5	6	5	3	3	4	5	28	4
PBX-9404	4	2	1	1	1	2	1	4	13	2
Composition B-3	5	3	3	4	4	4	5	1	21	3
Composition A-3	6	4	5	3	5	5	-	-		
TNT (Pressed)	7	6	4	7	-	-	6	6	36	5

* These two tests not included in sum total since no results are available for TNT.

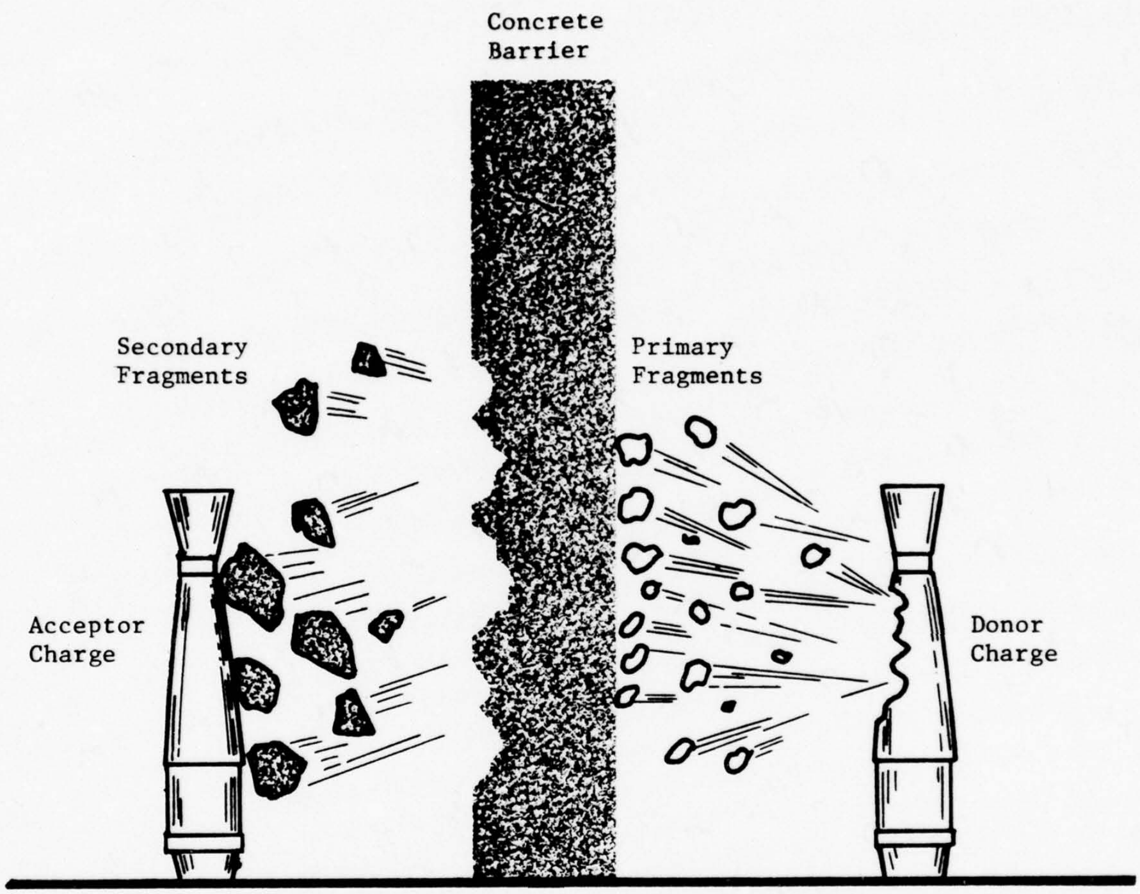

Fig 1 Schematic of secondary fragment impact

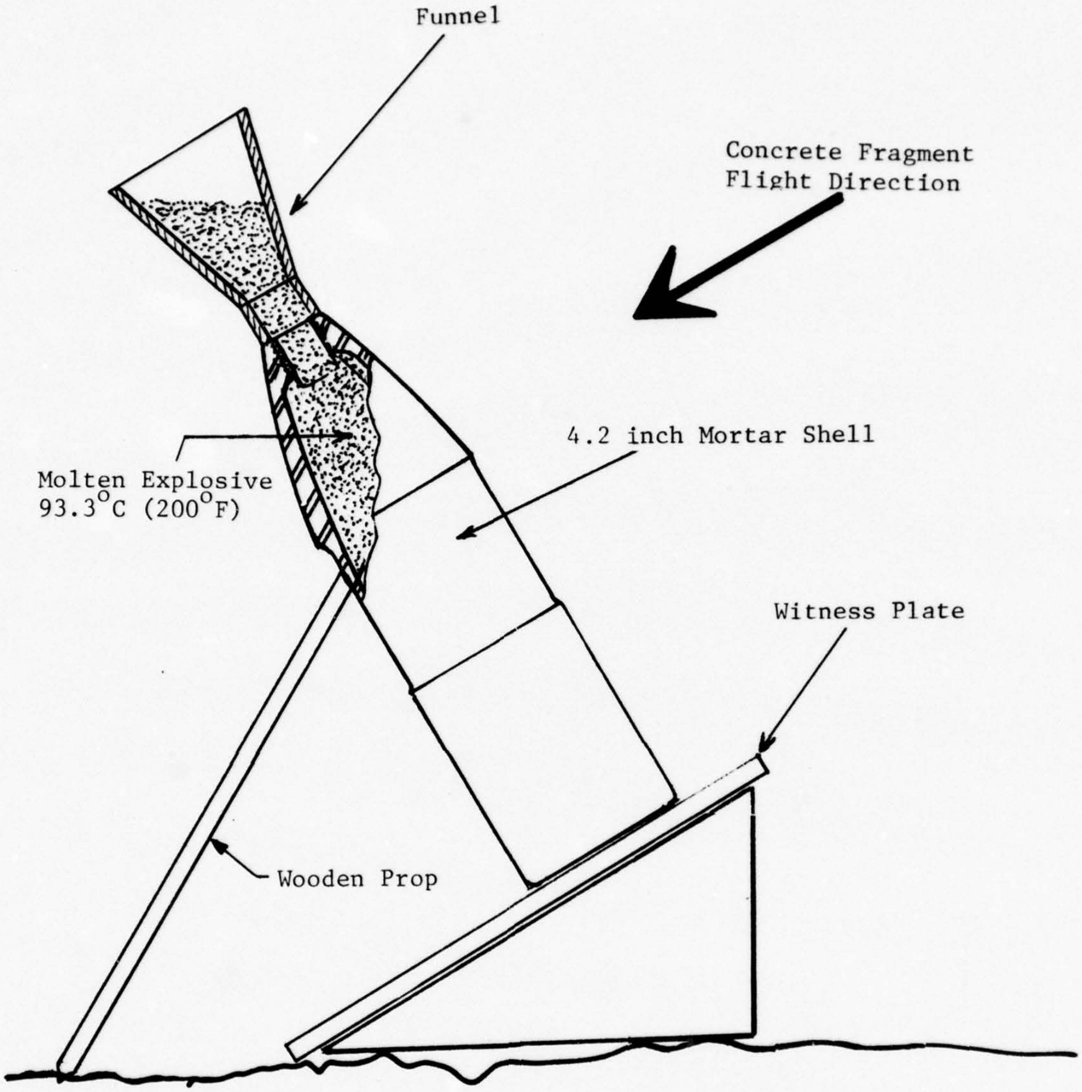

Fig 2 Test setup of a "just filled" configuration with loading funnel in place

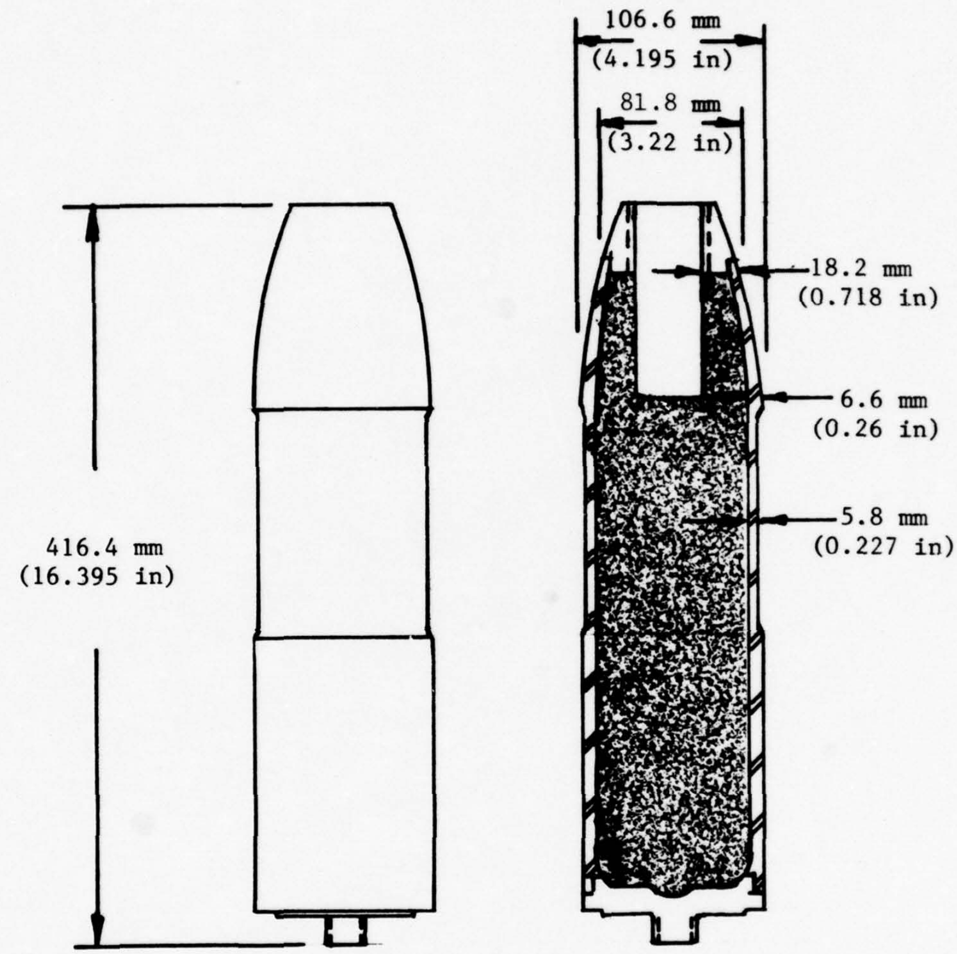

Fig 3   4.2 inch mortar shell (M329A1)

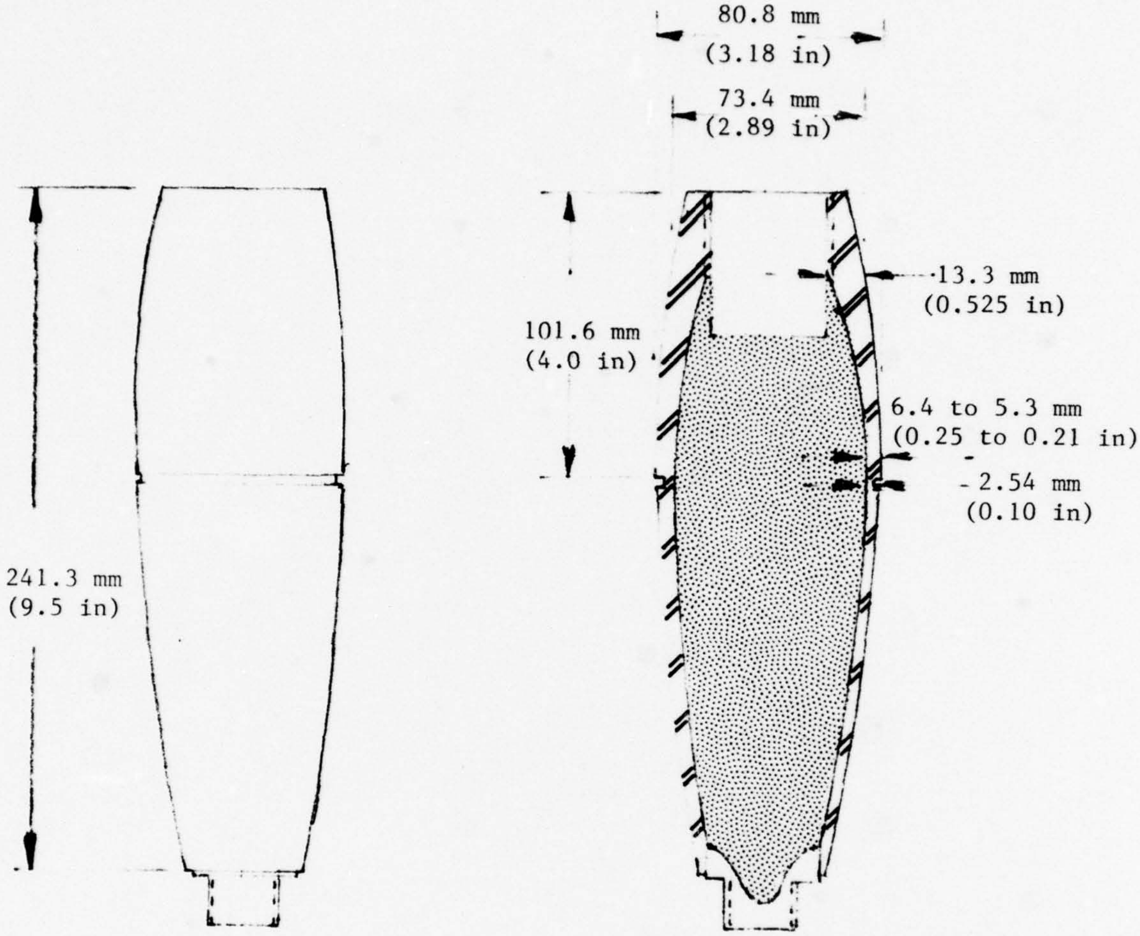

Fig 4 81 mm mortar shell (M362A1)

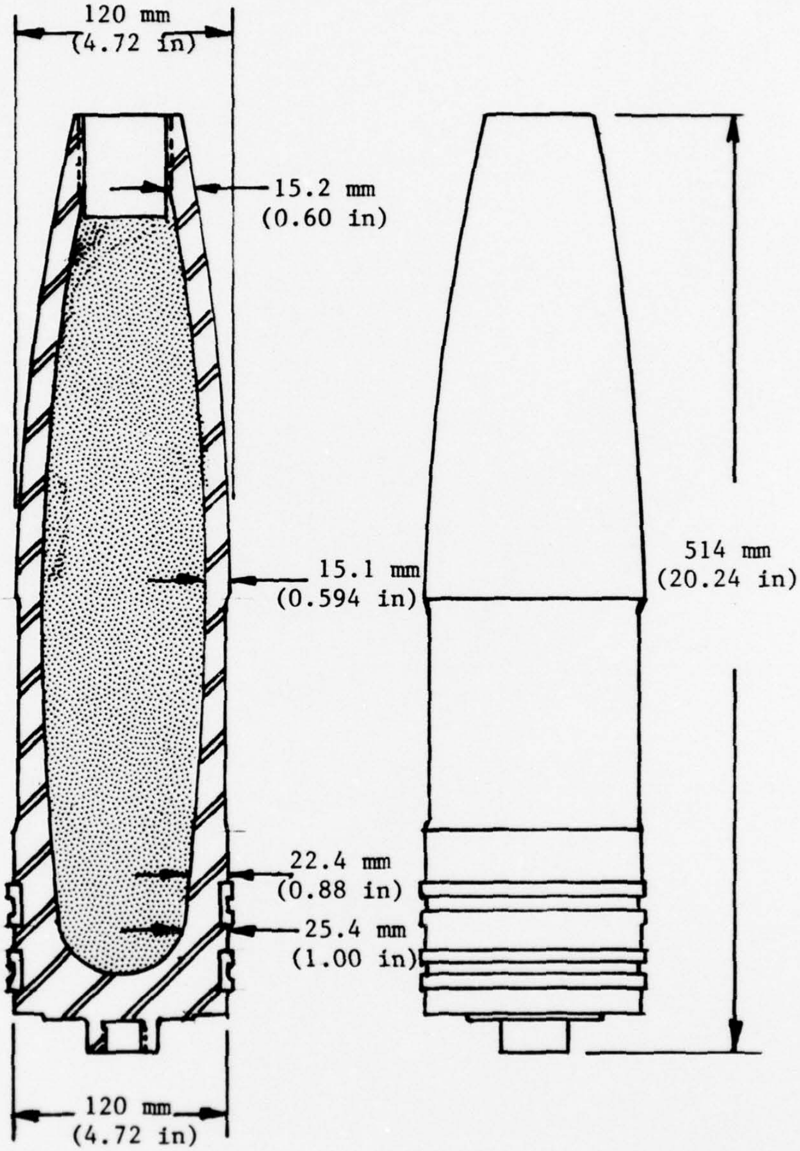

Fig 5 120 mm cannon shell (M356 T15E3)

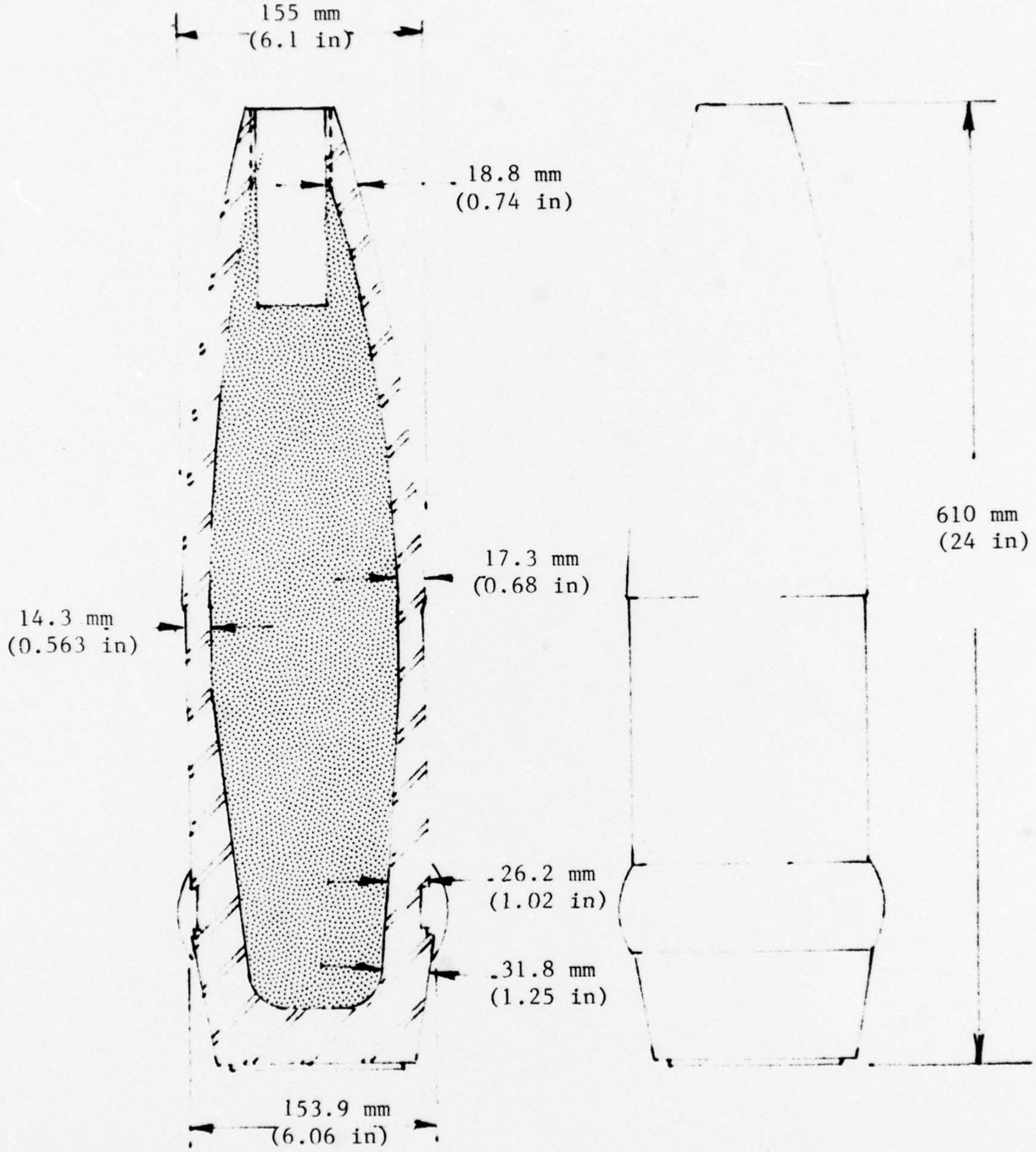

Fig 6 155 mm howitzer shell (M107A1)

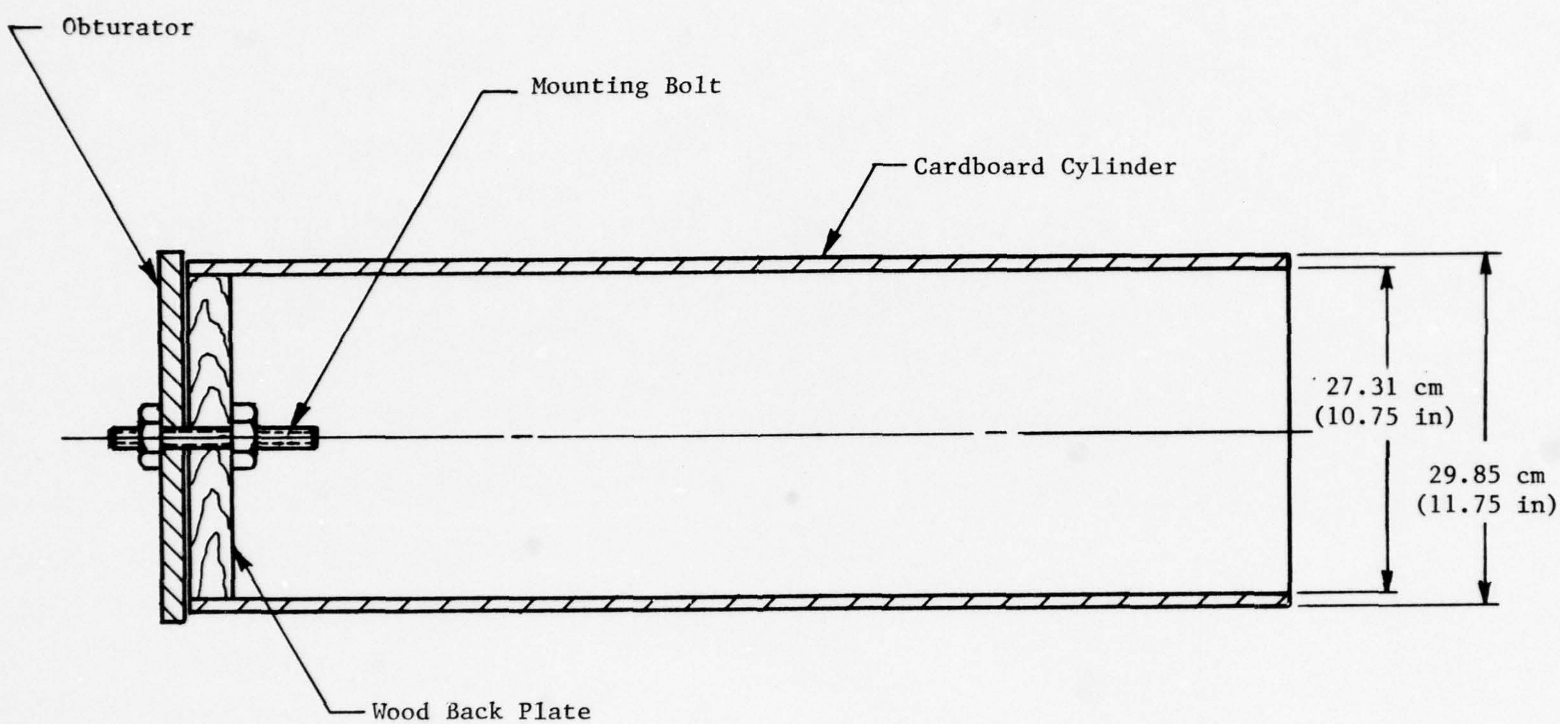

Fig 7 Concrete fragment container assembly

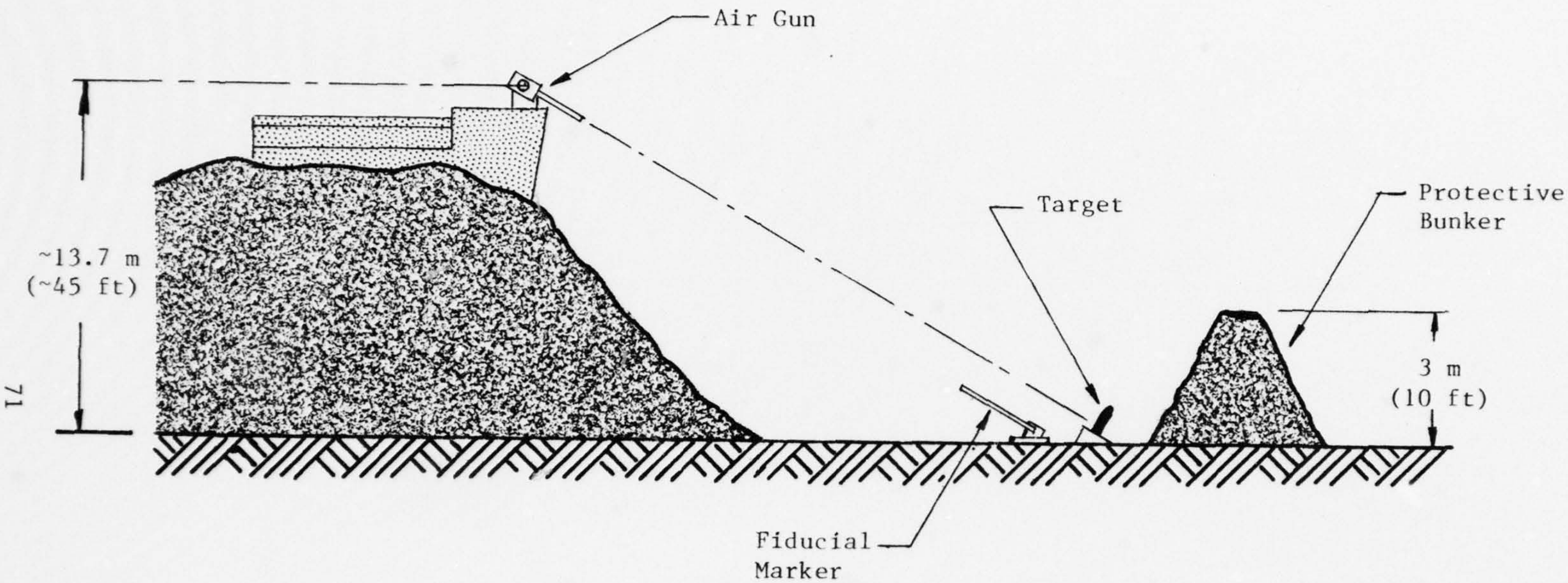

Fig 8 Secondary fragments impact test site

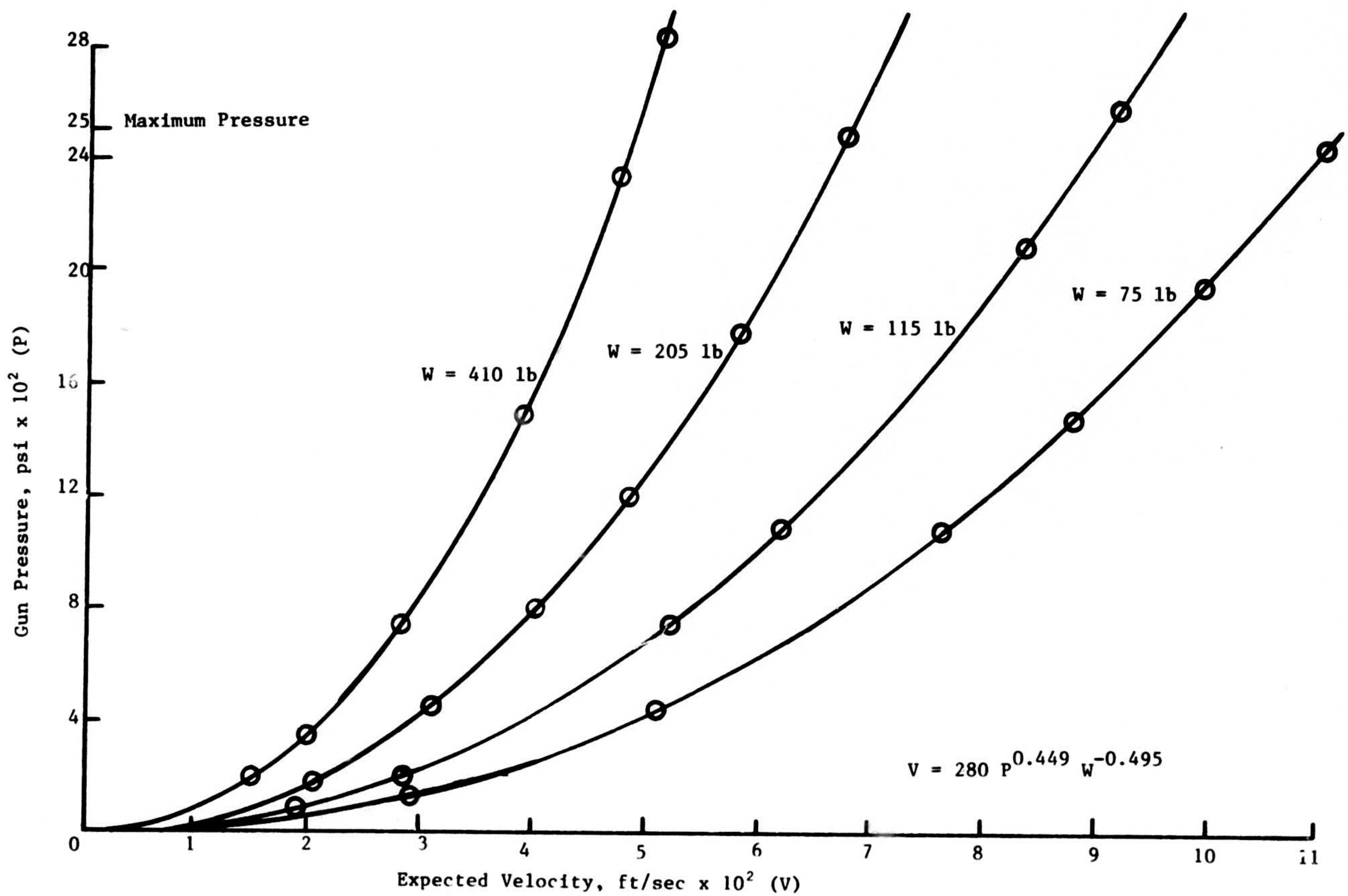

Fig 9 Air gun capability

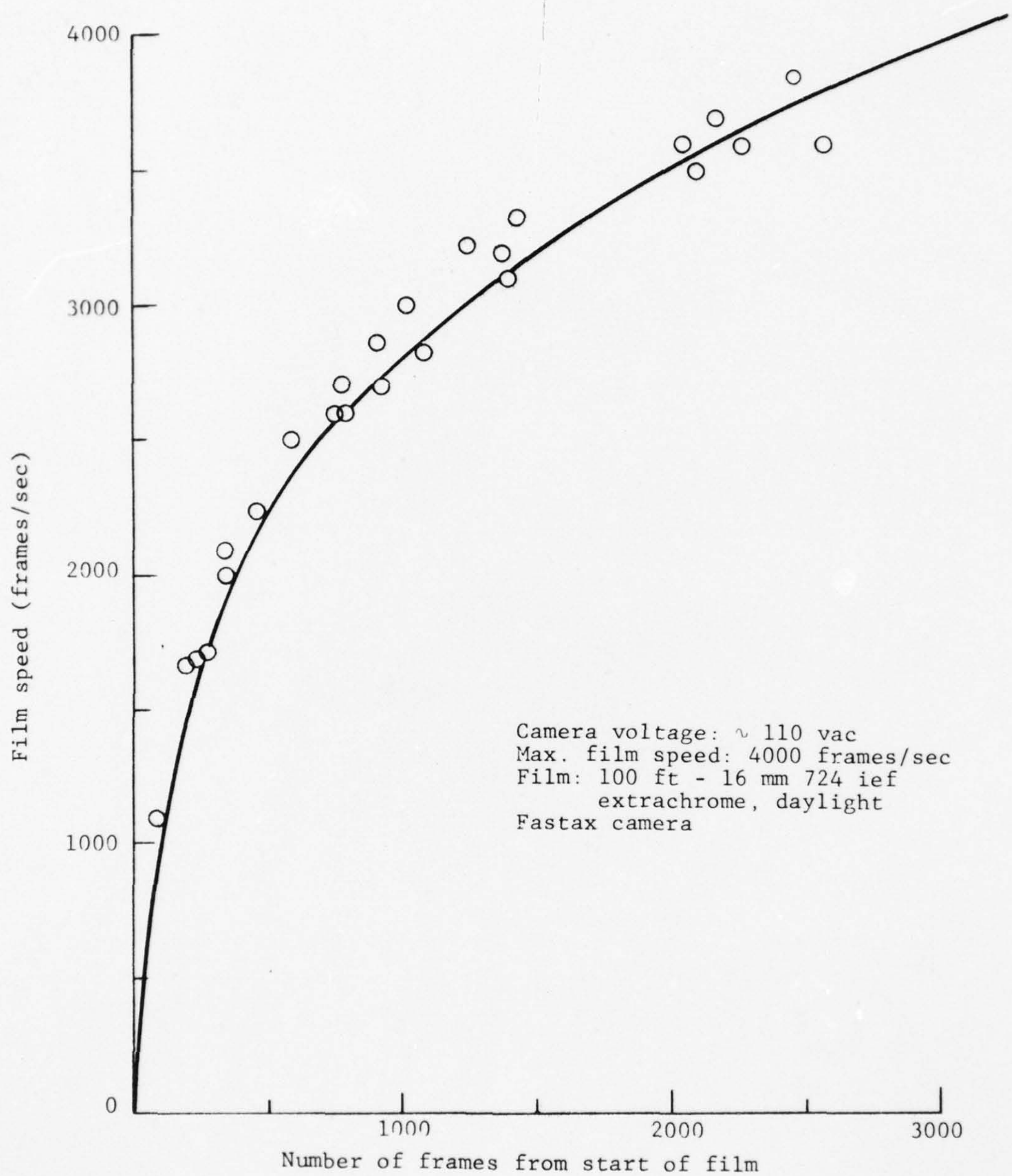

Fig 10 High speed Fastax camera characteristics

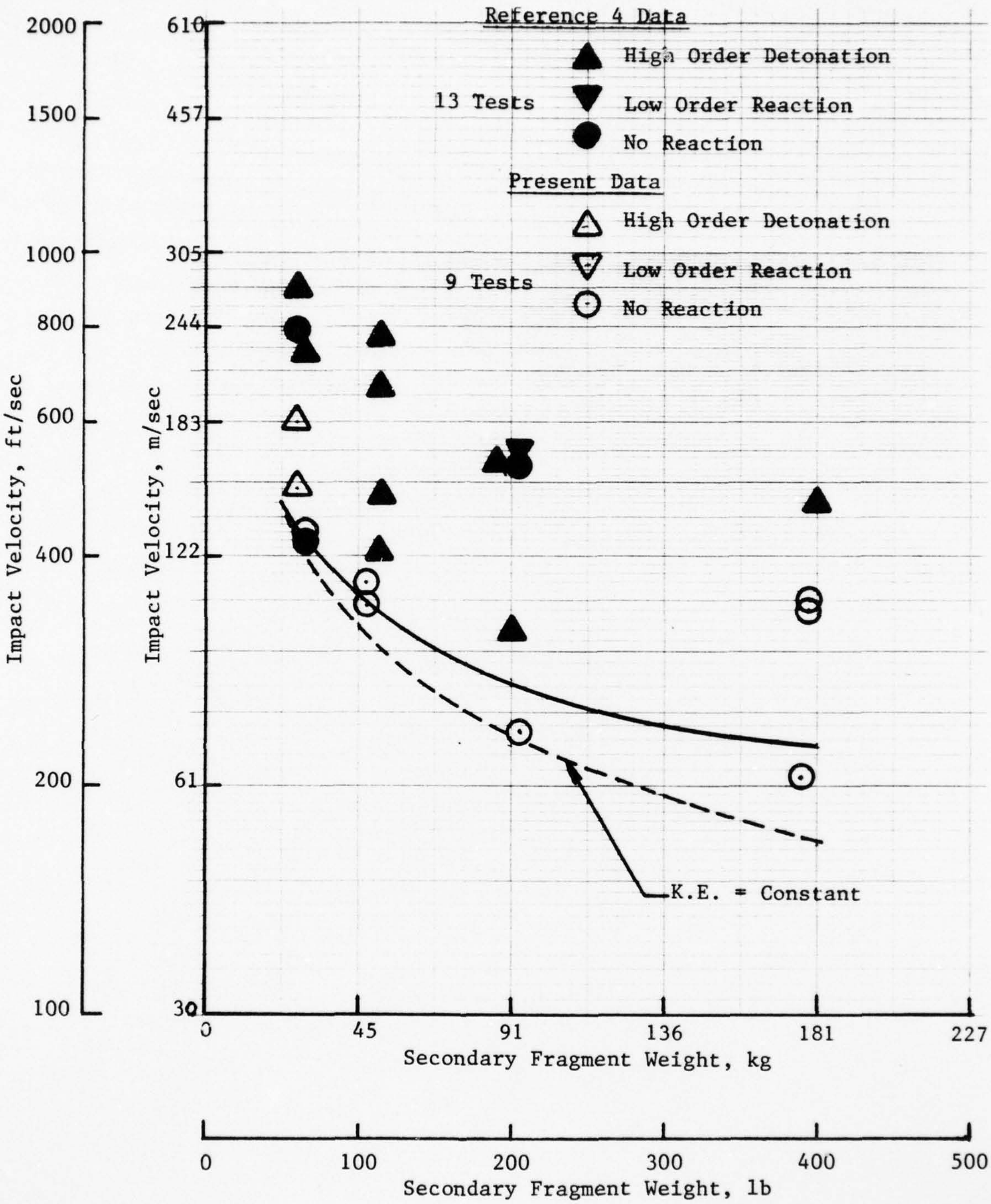

Fig 11 Secondary fragment impact results for 4.2 inch (M329A1) mortar shell, "just filled" condition with TNT at 79-88°C (174-190°F). Data in Table 3

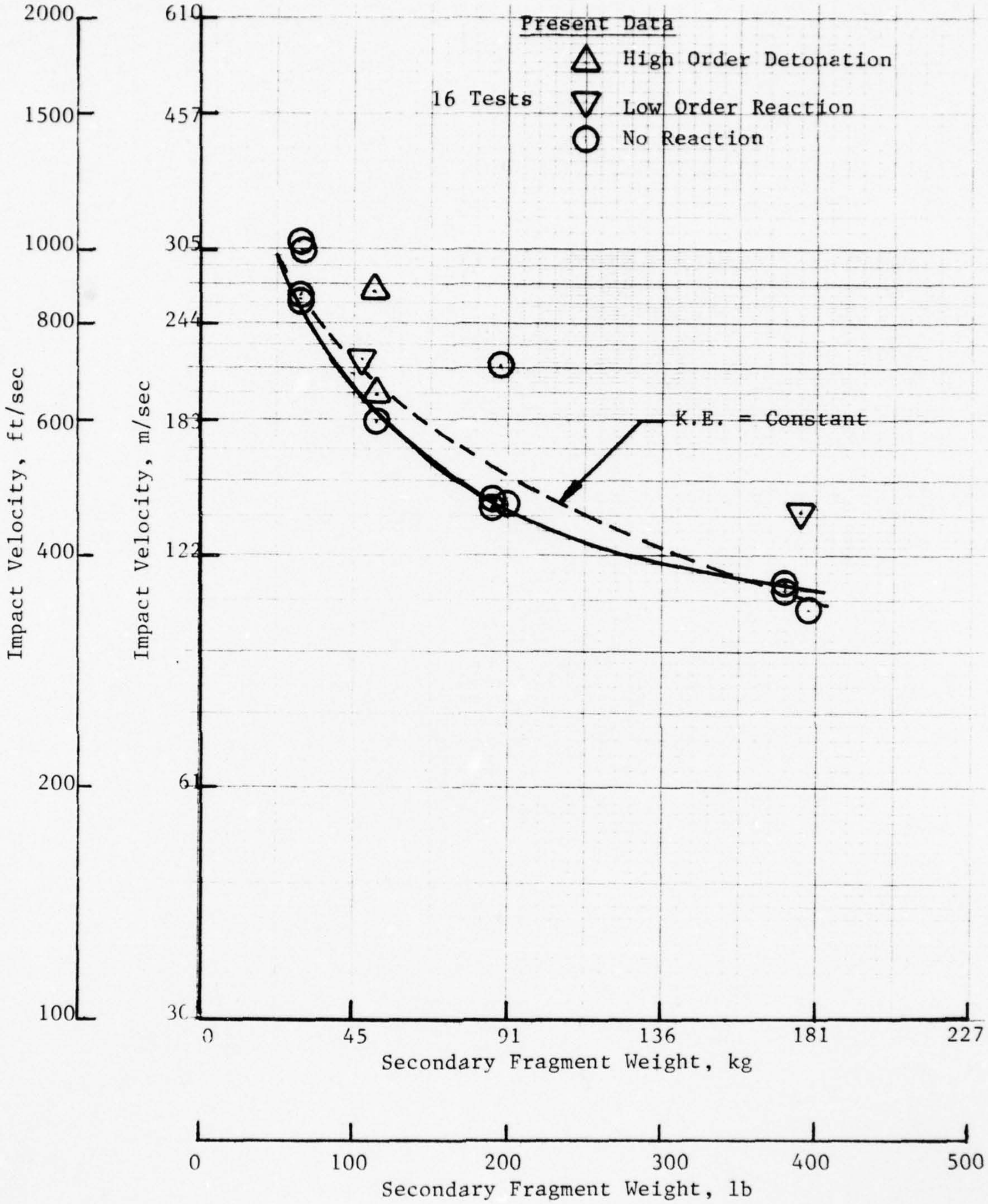

Fig 12 Secondary fragment impact results for 81 mm (M362A1) mortar shell, "just filled" condition with TNT at 74-85°C (165-185°F). Data in Table 4

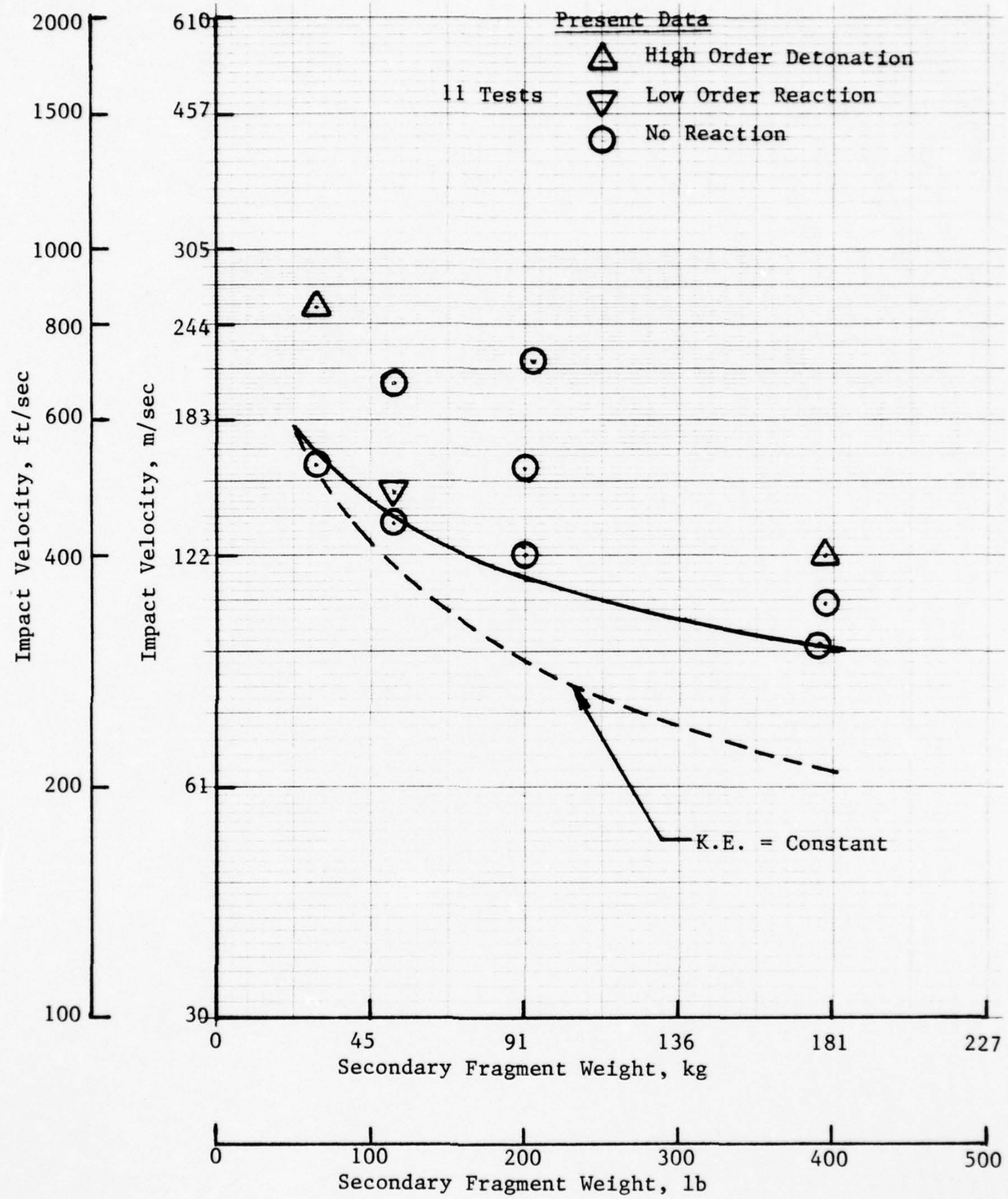

Fig 13 Secondary fragment impact results for 4.2 inch (M329A1) mortar shell, "just filled" condition with Composition B at 82-89°C (179-193°F). Data in Table 5

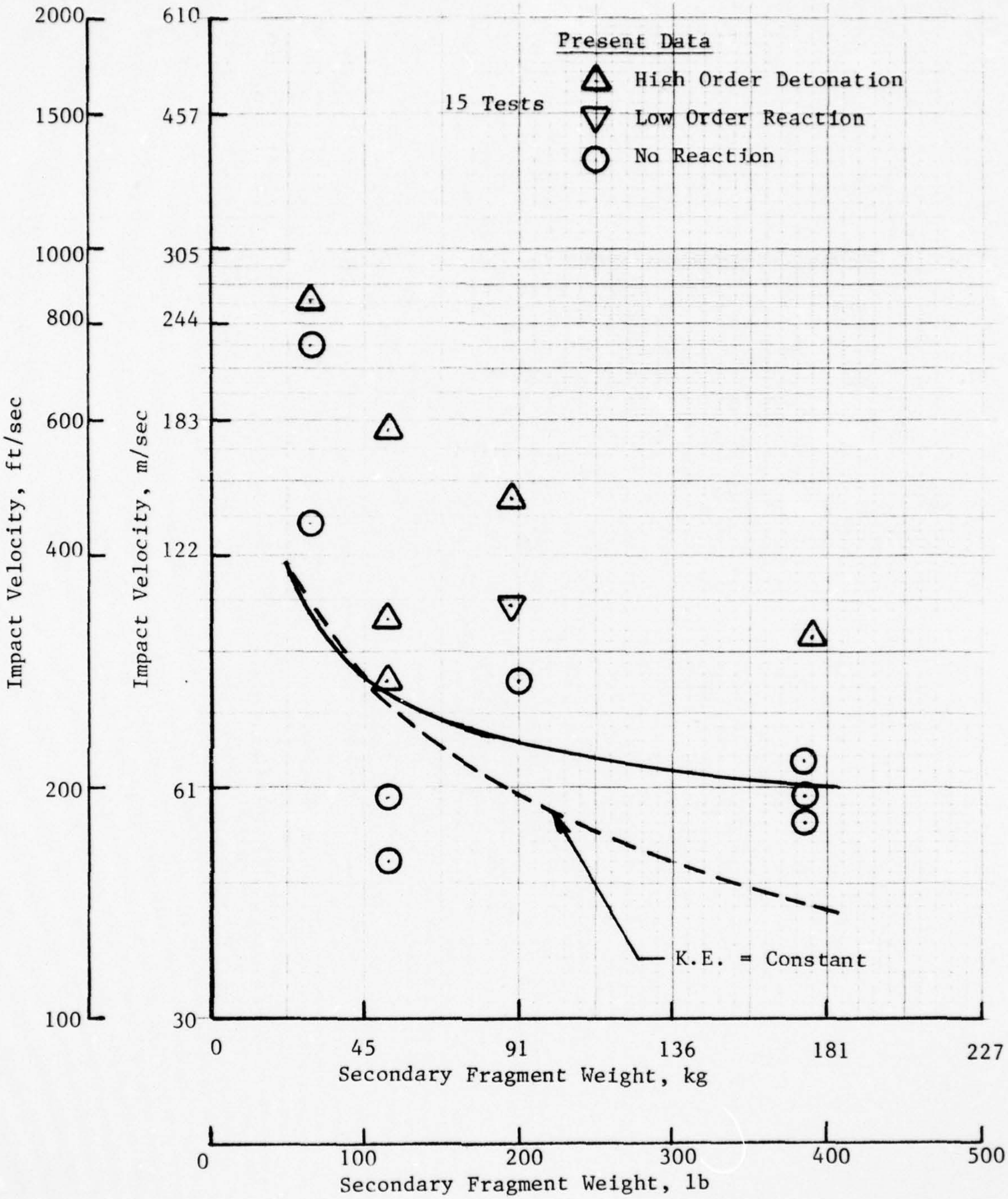

Fig 14 Secondary fragment impact results for 4.2 inch (M329A1) mortar shell, "just filled" condition with Cyclotol 75/25 at 82-102°C (180-216°F). Data in Table 6

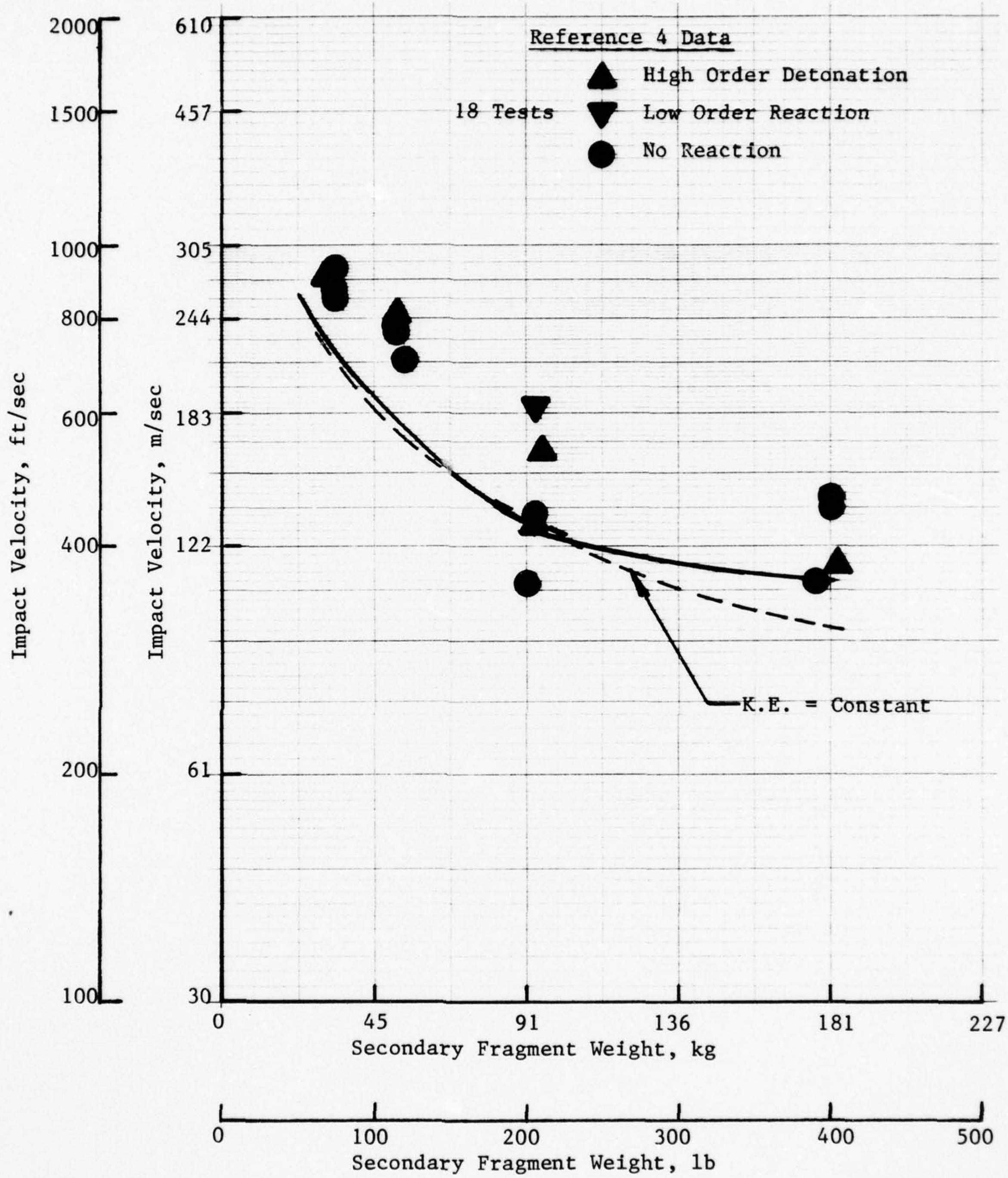

Fig 15 Secondary fragment impact results for 81 mm (M362A1) mortar shell, "just filled" condition with Compostion B at 64-88°C (148-190°F). Data in Table 7

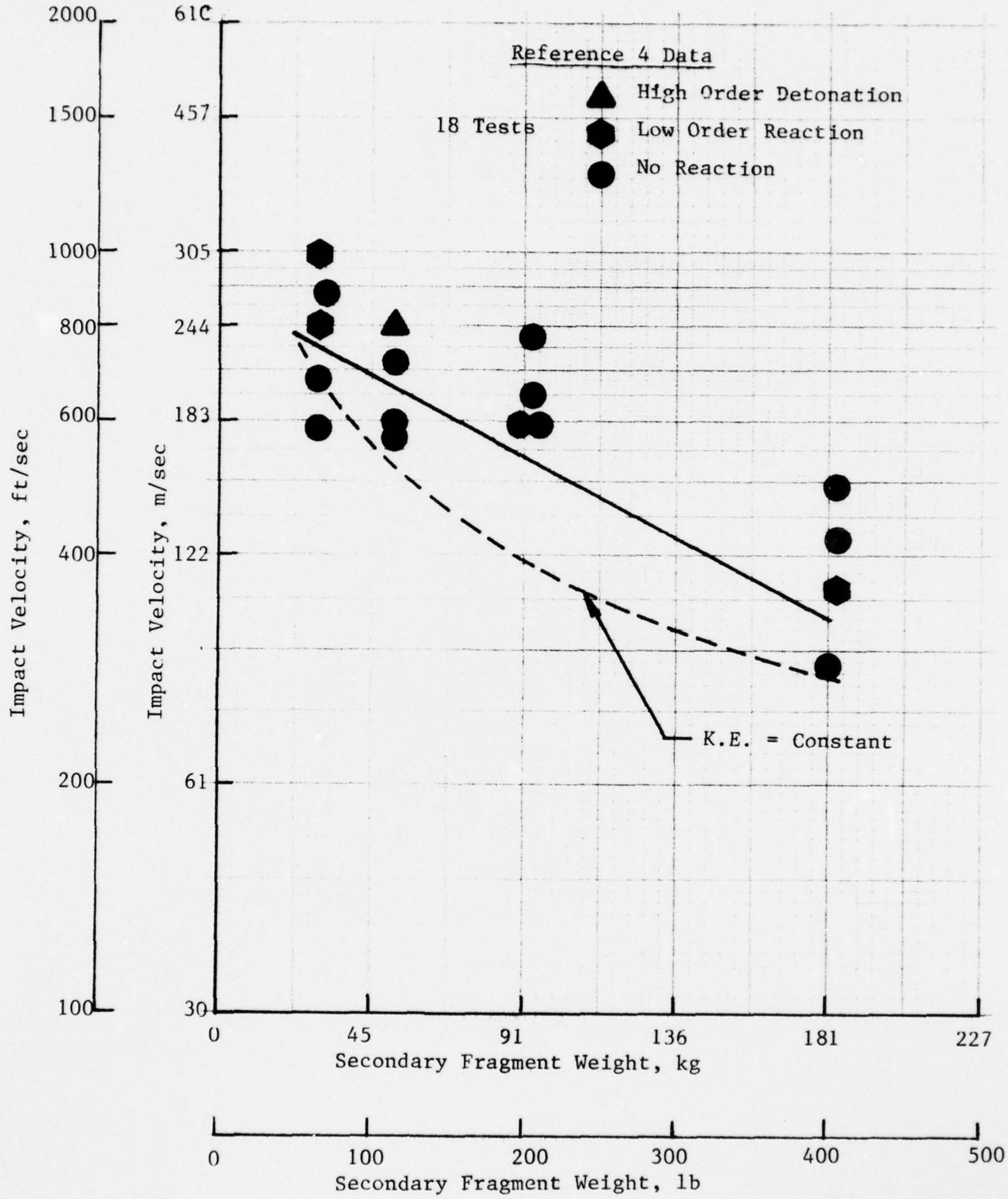

Fig 16 Secondary fragment impact results for 120 mm (M356 T15E2) cannon shell, "just filled" condition with Composition B at 71-82°C (160-180°F). Data in Table 8

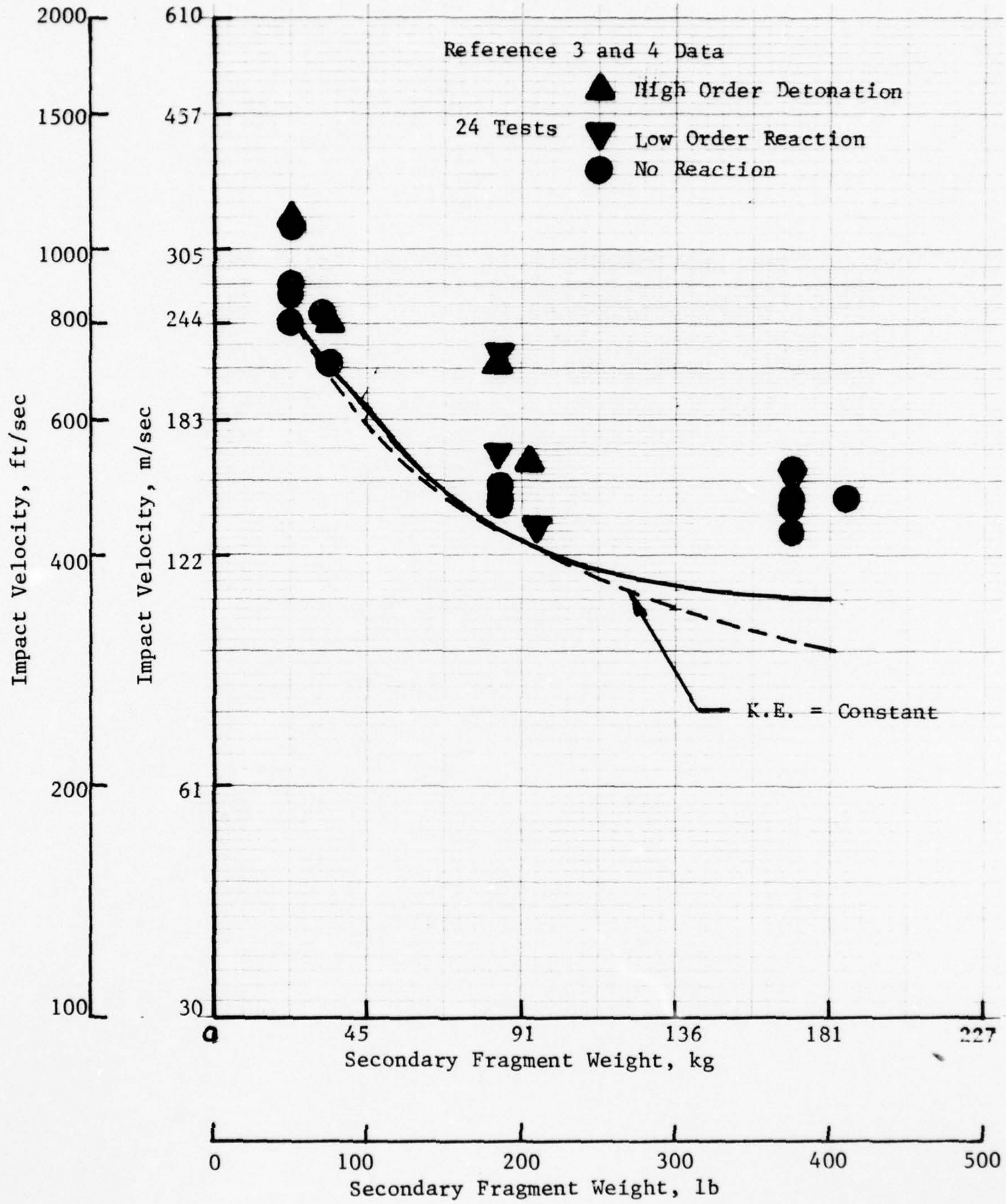

Fig 17 Secondary fragment impact results for 155 mm (M107A1) howitzer shell, "just filled" condition with Composition B at 77-88 °C (170-190 °F). Data in Tables 9 and 10

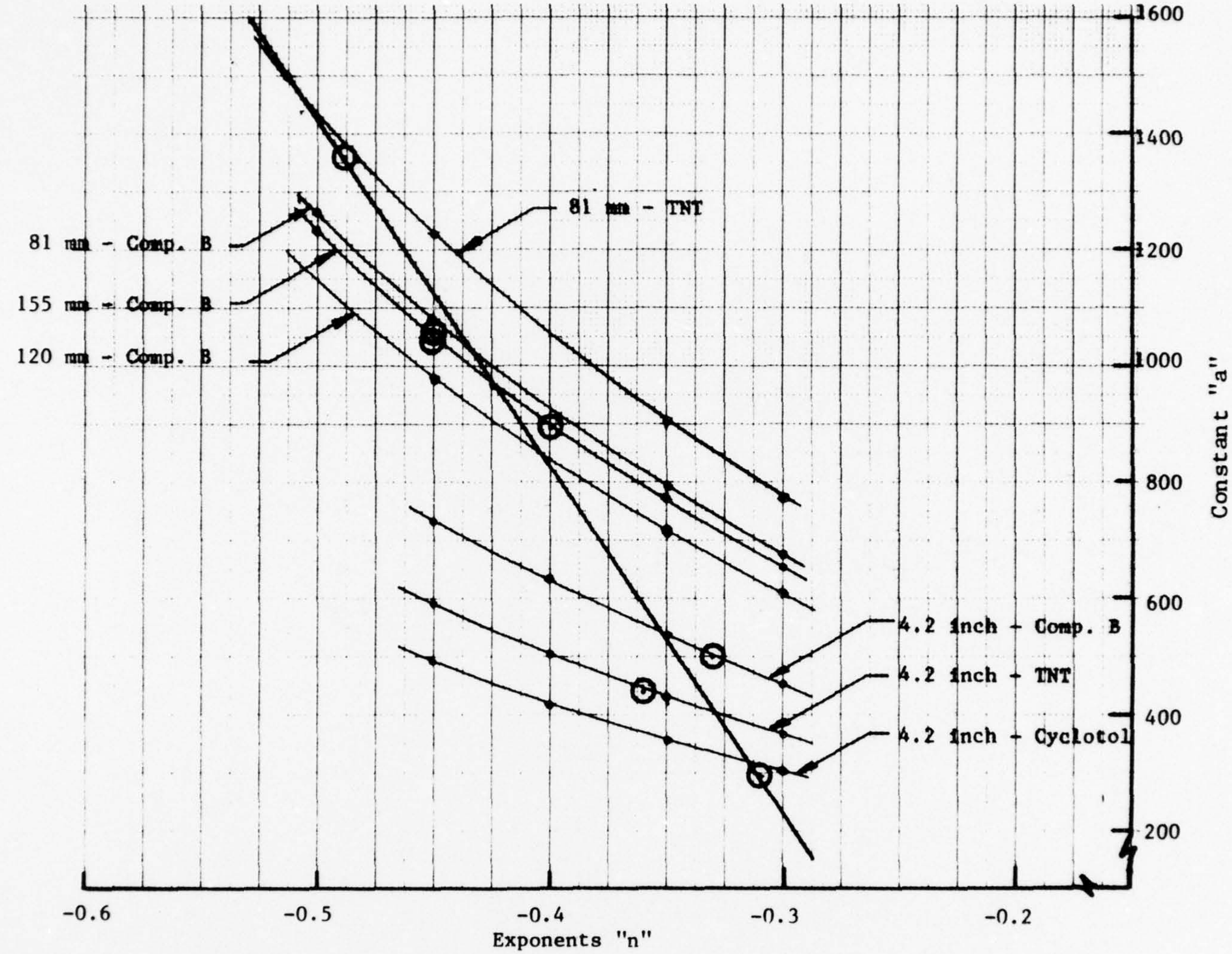

Fig 18 Plot of constants and exponents from derived power equations